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PRECAMBRIAN AND LOWER PALEOZOIC HISTORY OF THE SCOTTISH HIGHLANDS AND THE ROLE OF ABYSSAL FRACTURES

by

Ye. V. Pavlovskiy

On the basis of his review of the Pre-Cambrian and Lower Paleozoic, given in a preceding paper,[1] the author analyzes the structural development of Scotland during this time and describes the role of abyssal fractures.

* * * * *

The Eria platform is the oldest element in the entire system of large tectonic blocks of Scotland. Neither the stratigraphy nor the structure of the Lewisian complex, i.e., the fundamental complex (the lowermost structural unit) of this ancient platform has been worked out. The subdivision of the Lewisian complex into ortho- and paragneiss used by British geologists is largely formal, because both groups have rocks representing different metamorphic zones, as has recently been pointed out by S. Bubnov ([2], p. 90). Sedimentary rocks partially altered by metasomatism and metamorphism (for example, diopside rocks with spinel, etc.) apparently have been included in the orthogneiss group. It seems to me that a rock cannot be called an orthogneiss merely because its composition is similar to that of granite and quartz diorite ([43], p. 10). It is very probable that the original rocks might have been arkose, sandstone or argillite. The hornblende-garnet rocks usually considered as metamorphosed basic sills and lava flows may be diaphthorite of hypersthene gneiss of sedimentary origin, as has been convincingly shown by D. S. Korzhinskiy in the Stanovoy Range region of Eastern Siberia [5, 7]. At the same time, some basic and ultrabasic gneisses are undoubtedly orthogneisses, as indicated, for example, by the relicts with gabbroid texture.

The age relations between the ortho- and paragneiss have not as yet been made sufficiently clear. From my point of view, not all orthogneisses can be considered younger than all paragneisses just because on Coll and Tiree islands orthogneiss cuts through a sequence of paragneiss. Perhaps we are dealing here with later pre-Torridonian intrusions of foliated granites. Moreover, in the region of Loch Maree, judging by the section made by B. N. Peach [42], the orthogneiss lies beneath a series of paragneisses (Fig. 1). In the same region there are large pre-Torridonian overthrusts bringing the orthogneiss over the paragneiss.

It is noteworthy that in the vicinity of Loch Torridon and Loch Broom in the Scourie region [43, 48], the Lewisian gneiss exhibits primary stratification which reveals the presence of a system of somewhat irregular gentle folds trending northeast. Maps showing primary stratification in the gneiss on the banks of Loch Maree indicate that the rocks are gently folded, even horizontal in places.

A later, second period of folding in the Lewisian complex produced steep isoclinal folds trending northwest. According to Phemister [43], this folding is especially clear in the paragneiss of Loch Maree and Gairloch. The same northwest trend is characteristic of many crushed zones. A new foliation subordinate to the superimposed folds trending northwest was introduced in the gneiss. All these events undoubtedly occurred in Pre-Torridonian time [48]. Considering this, it may be supposed that in the structure of the lowermost tectonic unit,

[1] Ye. V. Pavlovskiy, A short review of the Pre-cambrian and Lower Paleozoic of the Scottish Highlands, Izvestiya, Akademiya Nauk SSSR, Ser. Geol., No. 6, 1958.

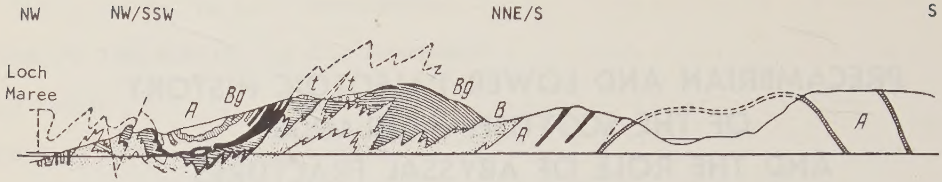

Fig. 1. Relation between orthogneiss and paragneiss in the region of Loch Maree, according to B. Peach. (From Phemister, [55].)

A -- orthogneiss, g -- paragneiss, Bg -- hornblende schist, t -- Torridon.

the basement of the Eria platform, there are at least two structural units, combined by many British geologists into a single Lewisian complex.

The lower unit, composed of sedimentary and igneous rocks metamorphosed at great depth, now represented by hypersthene gneiss, forsterite, pyroxene and phlogopite marble, metamorphosed basic and ultrabasic intrusives and the products of granitization, was crumpled into a system of folds striking northeast. The mineral associations in the rocks of the lower part of the basement of the Eria platform are comparable to those in the Archaean "Aldan-Slyudyanka" complex of Eastern Siberia studied by D. S. Korzhinskiy [5-7], Ye. V. Pavlovskiy [10], N.V. Frolova [16, 17], Yu. K. Dzevanovskiy [3], Ye. M. Laz'ko [9], N.G. Sudovikov [15] and others.

The second, upper, structural unit of the basement is composed of a series of sedimentary and igneous rocks metamorphosed under different thermodynamic conditions and resulting in the formation of kyanite and garnet schist and gneiss which were later cut by basic and ultrabasic dikes and various intrusions of synkinematic and postorogenic granites. The end of the second stage in the development of the ancient basement of the Eria platform was marked by the formation of a system of strongly compressed, northwest-trending folds complicated by overthrusts. Under the action of the dynamic and thermal processes occurring during the second stage, the high-temperature rocks of the lower structural unit underwent different degrees of retrograde metamorphism and developed a new foliation. It is possible, for example, that hypersthene gneiss was transformed into amphibole-garnet rocks.

In other words, using P. Michot's terminology [40], it may be said that the basement of the Eria platform is composed not of a single-cycle, but of a two-cycle or possibly polycycle complex.[1]

Using a rather remote example, I would say that the geologic history of the basement of the Eria platform is similar to what we know of the history of the Stanovoy Range of Eastern Siberia, which is composed of Lower Proterozoic formations and a complex of Archean diaphthorite of Aldan type reworked during the course of the intensive Lower Proterozoic orogeny (Korzhinskiy's Sayan-Stanovoy orogeny [7].

Comparison with nearby Norway does not give much information, as was noted by O. Holtedahl [33]. Attention should be directed, it seems to me, to the coincidence between the northeastern trends of the folds in the lower structural unit of the northeast of Scotland and the analogous structures (probably Svecofennids) of the Norwegian coast of the Skagerrak, composed of the Archean Kongsberg-Bamble formation.

In any attempted stratigraphic and structural subdivision of the Lewisian complex into two or more structural units, it would be especially important to study not only the facies but also the stages of progressive and retrograde metamorphism, as has been convincingly suggested by Sutton and Watson [48].

The northwest-trending fold system was the final deformation in the Eria region, and the occurrence of a flysch-like formation in the sedimentary series of the second unit of the basement, as exposed on Harris Island, was not accidental, as already

[1]After sending this paper to press, I read M. Kursten's paper (M. Kursten, Trans. Geol. Soc. 17, No. 1, 1957) in which he arrives at similar conclusions.

mentioned.[1] In later geologic history the Eria region lost its geosynclinal character and became a platform.

The subsequent development of the ancient platform is unusually interesting and distinctive. The base of the Eria platform deposits along its southeastern margin is the Torridonian sedimentary series.

The Torridon is usually correlated with the Moine series of the northern Scottish Highlands [12, 28], with the Jothnian of the Baltic shield [12], and lately with the Spargamite series of the Norwegian Caledonides [28, 33]. Let us consider the conditions of accumulation of the thick Torridonian sediments. On the map (Fig. 2), the exposed length of the Torridonian downwarp from Cape Wrath in the north to Islay Island in the south is approximately 350 km. The maximum exposed width of the downwarp along the line Loch Broom-Lewis Island is 80 km. In other places these dimensions are much smaller. Taking the horizontal component of the Moine Thrust (about 16 km) into consideration, we may assume that the Torridonian downwarp was much wider in its original state and that its southeastern margin is buried under the overthrust plate composed of folded Lewisian and Moinian rocks. The downwarp developed, therefore, in such a way that during the Diabaig epoch, the zone of intense subsidence was localized in the southern part of the Torridon area (southeastern end of the Isle of Skye) where the thickness of the Torridonian sediments is greatest (2100 to 2200 m). The thickness of the sediments decreases rapidly to the northeast, along the trend of the downwarp, diminishing to 150 m in the vicinity of Gairloch (50 km north of the Torridonian outcrops on the Island of Skye).

In the south (Iona, Colonsay and Islay islands), there probably existed a second, smaller Torridonian downwarp, also located on the margin of the Eria platform.

The monotonous uniformity of the sediments of the Diabaig formation, consisting mainly of fine-grained arkose, argillite and claystone with infrequent carbonate beds, especially in the upper part of the section, indicates rapid sedimentation in a shallow basin where deposition kept pace with subsidence of the basin. The rhythmic nature of sedimentation at the end of the Diabaig epoch is noteworthy and has been mentioned earlier.

What was the character of the sediments within the boundaries of the outer part of the deep Diabaig downwarp, now buried under the Moine thrust? It is possible that the conditions of sedimentation there were substantially different. What is the source of the pebbles of siliceous shale, chert, felsite of the Uriconian type porphyry and other exotic rocks in the overlying Applecross group? Rocks of these types and of suitable age are not found in situ either on the Eria platform or in the northern Highlands southeast of the Moine thrust. It seems to me that in the region of the Moine thrust a fault was already in existence in the Diabaig epoch which shaped the southeastern margin of the Eria platform. This fault zone, separating the platform from the Moine geosyncline to the southeast, contains granitic dikes and a typical complex of siliceous volcanics. Later, in the Applecross and Aultbea epochs, the fault zone became a zone of erosion and supplied detrital material to the region of the Torridonian downwarp to the north and the Moine geosyncline to the south. The Moine section, as we have seen, contains conglomerate in the so-called "Upper Psammitic Group," whose pebbles include exotic rocks analogous to those of the Applecross gravels.

The ancient Moine fault zone persisted into later times in the form of a positive structure, for the Lower Cambrian basal conglomerate of northwestern Scotland contains pebbles of the same exotic rocks, chert and felsite.

I believe that the post-Cambrian, prethrust intrusions of the Assynt region, the felsite sills, porphyries, lamprophyres, laccoliths and dikes of alkalic syenite, alkalic granite and other igneous rocks, were also most intimately related to the ancient fault zone upon which the complex structure of the Moine thrust was later developed.

Thus, it may be supposed that detrital material was delivered into the Torridonian downwarp not only from the north and northwest, as believed, for example, by Phemister [43], but also from the ancient Moine fault zone which bordered the Torridonian downwarp and the Eria platform on the southeast. The fault zone evidently developed over a long period of time, from the Torridonian epoch through the Early Paleozoic.

A new important stage in the development of the Torridonian downwarp occurred in the Applecross epoch. The entire northwestern coast of Scotland up to Cape Wrath became involved in intense subsidence, maximum subsidence occurring once again in the southwestern part of Ross-shire immediately adjacent to the Island of Skye. The Applecross group is a typical continental redbed formation. In its conglomerates, there are abundant

[1]See earlier paper in Izvestiya, No. 6, 1958.

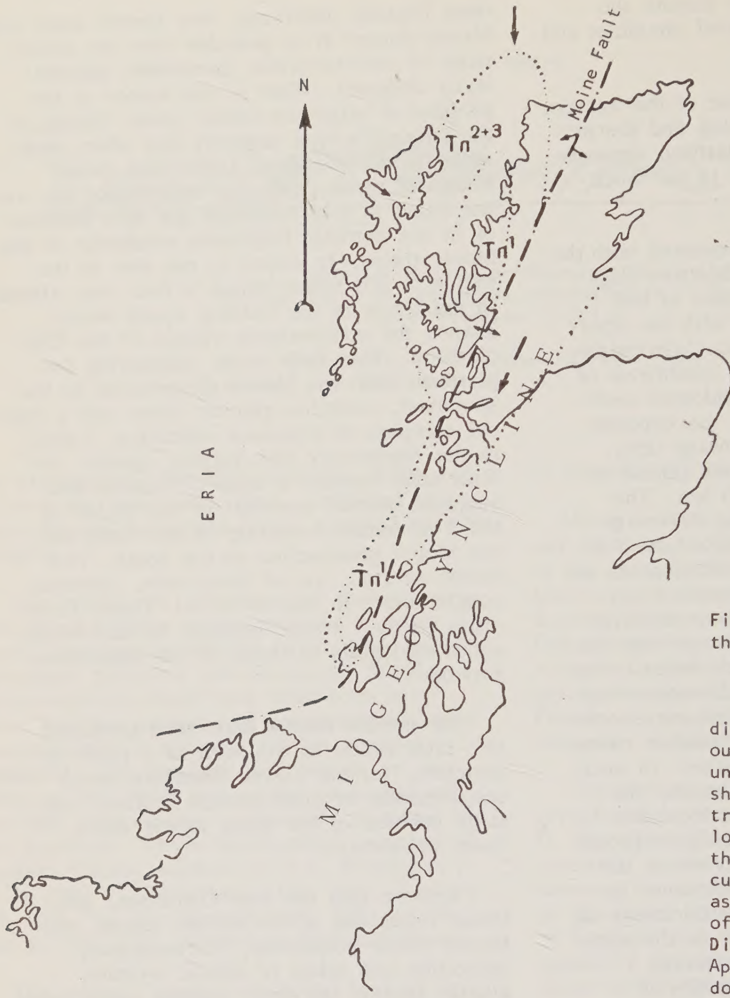

Fig. 2. Relation between the Eria platform and the Moine miogeosyncline.

The Great Glen Fault did not yet exist and the outline of Scotland looks unfamiliar. Short arrows show the direction of transport of sediments. The long interrupted arrow shows the dominant direction of currents in the Moine basin as determined by the study of cross-bedding. Tn^1 -- Diabaig downwarp, Tn^{2-3}-- Applecross and Aultbea downwarps.

pebbles of various magmatic rocks, including siliceous volcanics, derived evidently from the Moine fault zone. The red arkose and claystone of the Applecross group were formed, as described in the work of British geologists, from the detrital material brought from a land mass, composed of the rocks of the Lewisian complex, which bordered the downwarp on the north and northwest. The intensity of subsidence was as great in the southern part of the Torridonian downwarp as it was in the Diabaig epoch. As before, the rate of sedimentation was commensurate with the rate of subsidence. Analogous conditions and a similar rate of sedimentation persisted into the late Torridonian, through the Aultbea epoch. The Aultbea group redbeds are limited to the lower part of the section, and the upper part is composed of dark sandstone and claystone interbedded with carbonate rocks.

Thus, in the complete Torridonian section, redbeds occur in the upper formations of the Diabaig group, throughout the entire Applecross group and in the lower part of the Aultbea group. The upper half of the Aultbea section is composed of a gray, terrigenous, carbonate formation. The most complex group of formations is found in the lower and greater part of the Diabaig section. Here, there is a thick gray, terrigenous formation grading upward into gray, rhythmically-stratified, continental, carbonate beds, and still higher, into redbeds.

In light of what has been said, it may be supposed that the lower gray, terrigenous formation in the southeastern buried part of the downwarp grades along its strike into a siliceous volcanic formation which include different siliceous rocks and felsite.

Considering the lithologic composition of the Torridon beds, the form and orientation of the downwarp, and the relation of the Torridon to the Lewisian complex, it may be supposed that there is here a peculiar longitudinal, marginal downwarp resembling Kay's exogeosyncline [8, 37], developed on the margin of the platform and filled mainly with gray and red molasse. The development of this long, narrow downwarp was connected, probably, with gradual deformation and fracturing of the basement of the platform. An extensive zone of crushed gneiss, traceable in the Outer Hebrides along the shore of the Little Minch strait [30, 43], extends along the northwestern margin of the downwarp. The southeastern margin of the downwarp, as was shown earlier, was probably determined by the ancient Moine fault zone.

The transverse section of the downwarp, if the relatively thin Torridonian deposits on Lewis Island are considered, must have been assymmetrical. The zone of maximum subsidence was not in the middle of the downwarp but nearer to its outer, southeastern margin.

The upper layer of the sedimentary cover of the Eria platform is composed of Lower Paleozoic rocks. According to long-established tradition, the Lower Paleozoic deposits of northwestern Scotland are regarded as geosynclinal. It is here that the northern boundary of the British Caledonian folded zone containing the Northern Highlands and the Grampian Highlands is customarily drawn.

The idea that east of the region of the Durness limestones, i.e., within the Northern Highlands, thick clastic deposits accumulated simultaneously with carbonate rocks, and that the source of the clastics was a land mass lying still farther east was favored by O. Jones [34]. He believed that the narrow band of Lower Paleozoic rocks in northwest of Scotland represents only the western margin of a vast downwarp comparable in size to the Appalachian geosyncline. He even gave a special name to this hypothetical downwarp -- the Durness geosyncline.

Much more categorical in their tectonic ideas are V.V. Belousov and M.V. Gzovskiy [1], who base their constructions on Jones' interesting paper [34]. They separate in the British Caledonian geosyncline, "four intrageosynclines, each up to 100 km in width" ([1], p. 159). The northernmost "intrageosyncline" is the North Scotland geosyncline, which completely coincides with Jones' Durness geosyncline. In the opinion of Belousov and Gzovskiy, "throughout Cambrian and Ordovician time, the intrageosynclines broadened and subsided.... Volcanics began to occur in large quantity in the lower part of the section (Arenig - lower Bela)" ([1], p. 160). It may be said that these constructions and the authors' discussions of the pattern of development of the British Caledonian actually have nothing to do with a "North Scotland geosyncline." This is easily seen if one becomes familiar with the actual Lower Paleozoic section of Western Scotland.

The hypothetical Durness geosyncline of Jones must have been located somewhere in the Northern Highlands. Yet it is well known that there are no signs of any Lower Paleozoic deposits in that region, and therefore no signs of the corresponding geosyncline. It seems likely that in the northwest of Scotland, the remains of a Lower Paleozoic syncline filled with a relatively thin deposit of typical shallow-water platform sediments of Cambrian-Ordovician age have been preserved. The local Cambrian section is very similar stratigraphically and lithologically to analogous sections of different areas of the Siberian platform (Lake Nichatka, Malo-Torskiy graben [10] and others). The Lower Paleozoic syncline did not form at random on the Eria platform. It inherited its form, to some extent, from the Torridonian downwarp. The epicontinental character of the Lower Paleozoic basin is indicated by the unusual persistence of facies throughout the deposit, as noted by British geologists [43].

The deep Moine fault, which played such an important role in Torridonian time, became reactivated in the Lower Paleozoic and, first of all, served as the "zone of penetration" [23] along which alkalic magmas rose and intruded the Lower Paleozoic sediments. The clearly defined alkalic character of the Late Cambrian intrusives indicates their relationship to the younger alkalic intrusives of many other ancient platforms, for example the Baltic and Aldan shields.

The Precambrian and Paleozoic history of the Northern Highlands block was substantially different. As we have seen, the lower structural unit of this block is formed by the folded Lewisian, Sub-Moinian and Moinian complexes; a great thickness of Middle and Upper Devonian rocks occurs at the base of the upper structural unit.

An attractive idea suggests itself that the so-called Lewisian complex, distinguished with great difficulty from the Moine rocks in the "windows" of the Northern Highlands, the rocks of Lewisian type lying conformably on the Moine rocks in the central and northern parts of Sutherland, and the Sub-Moine gneiss and granulite constitute a single stratigraphic unit. Undoubtedly this series is older than the Moine, from which it is separated only by local unconformities, although in places the relationship between

the two series is conformable. The appropriate term Sub-Moine characterizes this entire series, which is probably intermediate in age between the Moine and Lewisian complexes. It is possible that southeast of the zone of the ancient Moine fault, outside the Eria platform, Torridonian folds were absent and sedimentation, which began in Lewisian time, continued in the Northern Highlands without interruption, or almost so, through the Moine period.

The thick series of clastic Moine beds in the Northern Highlands and farther south in the Grampian Highlands was evidently deposited in a miogeosyncline. Nowhere in the Moine section are there synchronous extrusives. As in the Torridonian downwarp, the Moine geosyncline subsided at about the same rate as sedimentation, resulting in lithologic uniformity throughout the series. Only two large rhythms are discernible in the sedimentary series of the Moine miogeosyncline, manifested by a change from pelitic to psammitic rocks upwards in the Moine section. The series is, in reality, a single clastic formation.

The existence of a barrier separating the Moine miogeosyncline from the Torridonian downwarp is confirmed by an interesting detail noticed by British geologists [43, 45]; a study of cross-bedding in the Moine series has shown that the direction of currents (north-northwest, south-southeast) in this shallow water basin followed the ancient Moine fault (Fig. 2).

Assuming that the stratigraphic correlation between Torridon and Moine is correct, I hold that the lower Torridonian formation (Diabaig) may be considered an analogue of the lower part of the Moine series, and the Applecross and Aultbea formation the stratigraphic equivalents of the upper half of the Moine sequence (Table 1). Such correlation seems possible to me because there are pebbles of exotic rocks (felsite) both in the Applecross conglomerate and in the conglomerate from the Upper Psammitic formation of the Moine series. The Upper Moine basin probably received products of erosion from the barrier which separated the Torridonian and Moine basins. The development of this barrier, as we have seen, may be credited to the tectonic activity in the zone of the ancient Moine fault where, at the Diabaig-Applecross time boundary (lower Moine-upper Moine), there occurred intrusions of porphyry and red granite and extrusions of felsite which produced the local siliceous, igneous formation. A further study of the pebbles from the Upper Psammitic formation of the Moine series in the Northern Highlands would be of exceptional interest.

The development of the Moine miogeosyncline and of the distinctive Torridonian downwarp (i.e., exogeosyncline) on the border of the ancient Eria platform proceeded in such a way that, by analogy with what is known of the history of younger geosynclines and their relationship with the adjacent platforms, it should finally have led to intense folding of the miogeosynclinal sediments, emplacement of intrusives and metamorphism

Table 1

Correlation of the Scottish and Scandinavian Precambrian after O. Holtedahl, J.G.C. Anderson, N.S. Shatskiy and A.A. Polkanov with some additions and changes.

<table>
<tr><th>Eria platform</th><th>Northern Highlands of Scotland</th><th>Grampian Highlands of Scotland</th><th>Norwegian Caledonides</th><th>Baltic shield</th></tr>
<tr><td>Cambrian</td><td rowspan="2">Hiatus</td><td>Upper Dalradian-Cambrian</td><td>Cambrian</td><td>Cambrian</td></tr>
<tr><td>Hiatus</td><td>Lower Dalradian</td><td>Upper Sparagmite</td><td rowspan="2">Hiatus</td></tr>
<tr><td>Upper Torridon: Aultbea and Applecross</td><td>Upper Moine</td><td rowspan="4">Upper Moine</td><td rowspan="2">Lower (pretillite) Sparagmite</td></tr>
<tr><td>Lower Torridon: Diabaig</td><td>Lower Moine</td><td>Jothnian Trösil</td></tr>
<tr><td>Hiatus</td><td rowspan="2">Sub-Moine</td><td rowspan="2">Fundamental complex</td><td>Hiatus</td></tr>
<tr><td>Lewisian</td><td>Fundamental complex</td></tr>
</table>

at the end of this period in their history. However, as the majority of British geologists believe, and with sufficient reason, this final stage common to all geosynclinal regions probably occurred here much later, in the second half of the Paleozoic. The Moine geosyncline, within the Northern Highlands, having accumulated a great mass of clastic sediments and having caused the development of a large longitudinal Torridonian downwarp, suddenly lost its geosynclinal character, its mobility, and became dormant for a long time. During a long period of time, covering the early Dalradian (Riphaean), late Dalradian (Cambrian) and the beginning of the Ordovician, the marginal part of the Moine miogeosyncline in the region of the Northern Highlands was dry land, an area of marginal uplift and supplier of clastic material to the neighboring Dalradian geosyncline to the south. At present there is no evidence for the former existence of Dalradian and Ordovician geosynclinal deposits in the Northern Highlands. Apparently no geosynclinal sediments were deposited there during Riphaean, Cambrian and Ordovician time.

If so, then the Northern Highlands block, involved for a long period of time in the intense Caledonian folding with all the associated phenomena, represents a very distinctive part of the Caledonides. It is possible that the exceptional complexity of the Caledonide structures in the Moine series of the Northern Highlands may be ascribed to the special very distinctive pre-Caledonian history of the region.

What is the explanation of this unusual finale to the development of the Moine miogeosyncline? It seems to me that a reasonable answer lies in the correct evaluation of the role and age of the Great Glen fault and in analysis of the development of the Grampian Highlands during Precambrian and Paleozoic time.

The lower structural unit of the large Grampian block, unlike the previously described blocks, includes the Moine series, the lower and upper Dalradian sediments and Ordovician rocks.

A very complete Proterozoic section exists here. Besides the Moine series dominant in the Northern Highlands, the Grampians also contain the lower Dalradian, which is equivalent to the Sparagmite formation of Scandinavia [28, 33] and probably to the Riphaean of the Russian platform and the Urals [19, 21, 22]. Within the Eria platform, as well as on the Baltic shield, the lower Dalradian (i. e., upper Sparagmite or Riphaean) marks the interval between the fossiliferous Cambrian and the Torridonian, which, in part at least, corresponds to the Jothnian of Scandinavia (see Table 1). The distinguishing feature of the Dalradian, besides the occurrence in its lower part of a boulder-bearing horizon [28, 33], is the clearly expressed rhythmic stratification of the upper carbonaceous formation. The carbonaceous formation is part of a thick flysch deposit in which Cambrian sediments are abundant.

We have seen that the composition of the Dalradian (Cambrian) is quite varied and distinctive. Here, thick flysch sediments are interbedded with persistent limestone beds (Loch Tay) and spilite, keratophyre, tuff and possibly volcanic ash. The flysch accounts for the greatest thickness of the section. The accumulation of the flysch was interrupted by periods of relative quiescence in the tectonic regime of the Cambrian basin during which carbonate rocks were deposited everywhere. The regime of the flysch basin was interrupted also by intense volcanic activity. Many kilometers of sedimentary and volcanic rocks of the lower structural unit of the Grampians are topped by Caradoc deposits.

Thus, clastic rocks of the Moine series lie at the base of this section, having been accumulated in a miogeosyncline. The same miogeosynclinal regime probably persisted during deposition of the lower Dalradian series (Late Proterozoic, Riphaean, early Cambrian time, see Fig. 3). During the Cambrian (Late Dalradian) in the region of the Grampians, the miogeosynclinal regime changed sharply into a eugeosynclinal regime. The deposition of a flysch of great thickness in the Cambrian eugeosyncline was interrupted by extrusion of lavas and rather brief periods of relative quiescence marked by the deposition of carbonate rocks (Fig. 4). During the Ordovician the area of the basin of sedimentation was sharply diminished. The siliceous volcanic formation of Arenig time, deposited only in a narrow zone of the southeastern Grampians, is evidently directly related to the development of the Boundary Fault. Later, this narrow Boundary Fault zone received thin local accumulations of Caradoc clastics.

As we have already seen, the structure of the Grampian Highlands is very peculiar.

In accepting the existence of objective data furnishing the basis for E. Bailey's ideas [30] concerning the extreme complexity of the nappes of the southwestern Grampians, I must remark that these ideas are not consistent with the great simplicity of the contours of the metamorphic zones as shown on the maps by Barrow, W. Kennedy and Tilley. During our excursion, several days were devoted to the geology of the rather large northern part of the Grampians recently studied by J. G. C. Anderson [29]. This area

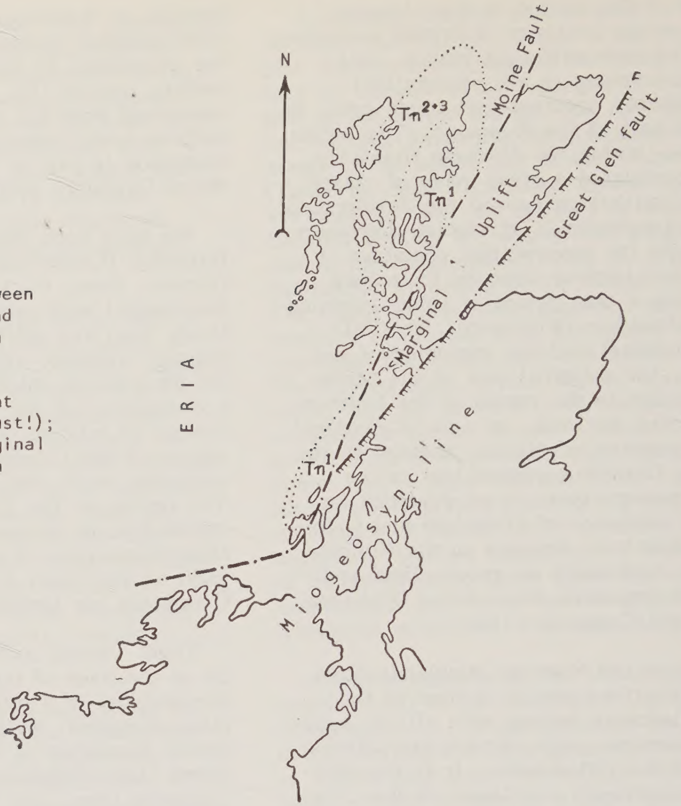

Fig. 3. Relation between the Eria platform and the Lower Dalradian miogeosyncline.

Appearance of the Great Glen fault (not a thrust!); appearance of the marginal uplift in the Northern highlands.

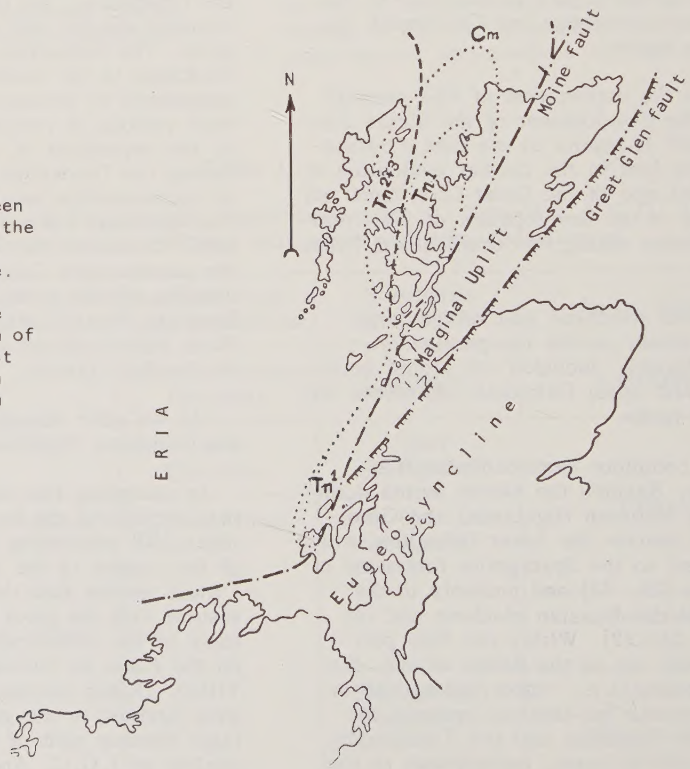

Fig. 4. Relation between the Eria platform and the Cambrian (Upper Dalradian) eugosyncline.

Appearance of a gentle downwarp on the margin of the platform (northwest Scotland); filled with shallow-water Cambrian sediments (Cm).

covers the upper reaches of the Spey River (from Aviemore up) and the watershed of the Spey, Roy and Spean Rivers. It is composed of the Moine series metamorphics and the lower formation of the Dalradian series cut by "ancient" and "young" granitic intrusions and is directly adjacent to the region of complex nappes and overturned folds with their peculiar faults described by Bailey. According to Bailey, the region of the upper Spey River lies along the strike of these complex structures. The structure of the region we visited is relatively simple and was admirably described by Anderson. The Moine and Dalradian rocks are crumpled into relatively simple, tight linear folds of isoclinal type. They strike northeast. There are no signs either of recumbent folds or of the peculiar faults (slide faults, fold faults) which are found in the neighboring areas southwest of the area of Anderson's map. It is apparent that the complex nappes described by Bailey and other investigators are not characteristic of the Grampian Highlands as a whole but are only locally developed.

Why did the Grampian block evolve in a distinctive way? Why at the end of the Precambrian (Riphaean) and in the beginning of the Early Paleozoic (Cambrian, Early Ordovician) did it develop so differently from the Northern Highlands block?

The northwestern boundary of the Grampians is the linear Great Glen fault zone. An interesting study by W. Kennedy is devoted to this fault [38]. According to him, the Great Glen fault is a gigantic strike-slip fault which shifted the Grampians about 100 km to the northeast (65 miles) with respect to the Northern Highlands. Kennedy cited convincing evidence for the nature of movement on the Great Glen fault. The main proofs are: fracturing and displacement of the parts of the once continuous distinct Caledonian Strontian-Foyer granite massif; lateral displacement of the Moine zone of migmatization; and displacement of the metamorphic zones. Kennedy believes that the shifting of the two parts of Scotland occurred in the Carboniferous as a result of the great Hercynian (Armorican) stresses. He shows also that the Great Glen fault zone is still active (in terms of localization of earthquake foci). The results of activity of this large fault are preserved in the Mesozoic, especially Kimmeridgian sections [30] on the two sides of the fault. Judging by the available data, the Great Glen fault belongs to the type of major crustal dislocations which are known in the Soviet literature as abyssal faults because of the works of A.N. Zavaritskiy [4], N.S. Shatskiy [18-20] and A.V. Peive [13, 14].

Kennedy believes that the Great Glen fault originated in the Carboniferous. In Bailey's opinion ([30], p. 242), the "birthday" of this fault is not yet definitely known. During the discussion of Kennedy's paper at a meeting of the Geological Society of London ([38], p. 73), Bailey presented good evidence for a pre-Middle Devonian age for the main horizontal displacements. Indeed, the geologic map of Scotland [50] shows no displacement of the Middle Devonian or younger formations along the fault. Most likely, the shifting of the large blocks of Scotland along the Great Glen fault occurred during the interval between the emplacement of the Caledonian granite of the Strontian-Foyers massif and the Middle Devonian.

Studies of abyssal faults [13, 14, 18, 19] show that they develop over long periods of time and are very old, their beginnings usually being traceable to the Precambrian. It seems to me that the Great Glen fault, which caused gigantic horizontal movements in the beginning of the Middle Devonian, had already been in existence as a zone of deep fracturing or perhaps a large flexure, and certainly as a zone of penetration, for a very long time. It may be assumed with a considerable degree of assurance that it is the formation of this deep zone of fracturing on the Moine-Dalradian time boundary that determined the course of development of the Grampian and Northern Highlands blocks. By the end of Moinian time the zone of the ancient Great Glen fault separated the Northern Highlands block from the southern part of Scotland even before horizontal movements began, and the appearance of this fault zone completely changed the pattern of development of the Moine miogeosyncline (Figs. 2, 3). In the Northern Highlands block, a part of the miogeosyncline was changed into a marginal uplift along the boundary of the ancient Eria platform. Southeast of the Great Glen abyssal fault zone and under its direct influence the regime of the Moine miogeosyncline was changed to the eugeosynclinal regime so clearly expressed in the Cambrian (upper Dalradian) stage of development of the Grampian Highlands. It is easy to imagine that the Great Glen fault zone served as the channel for the magmatic melts which fed the voluminous extrusions of basic lava in the Grampians in the early Cambrian (upper Dalradian beds). The exceptionally complex folded structures in the Dalradian series (Riphaean and Cambrian) described by Bailey from the southwestern part of the Grampian Highlands, the intrusion of a series of dikes and a group of peculiar ring-like granitic bodies of the Ben Nevis type in the immediate vicinity of the Great Glen fault, are probably not accidental. They have, it must be assumed, an intimate genetic relationship with the presence and activity of the ancient Great Glen abyssal fault.

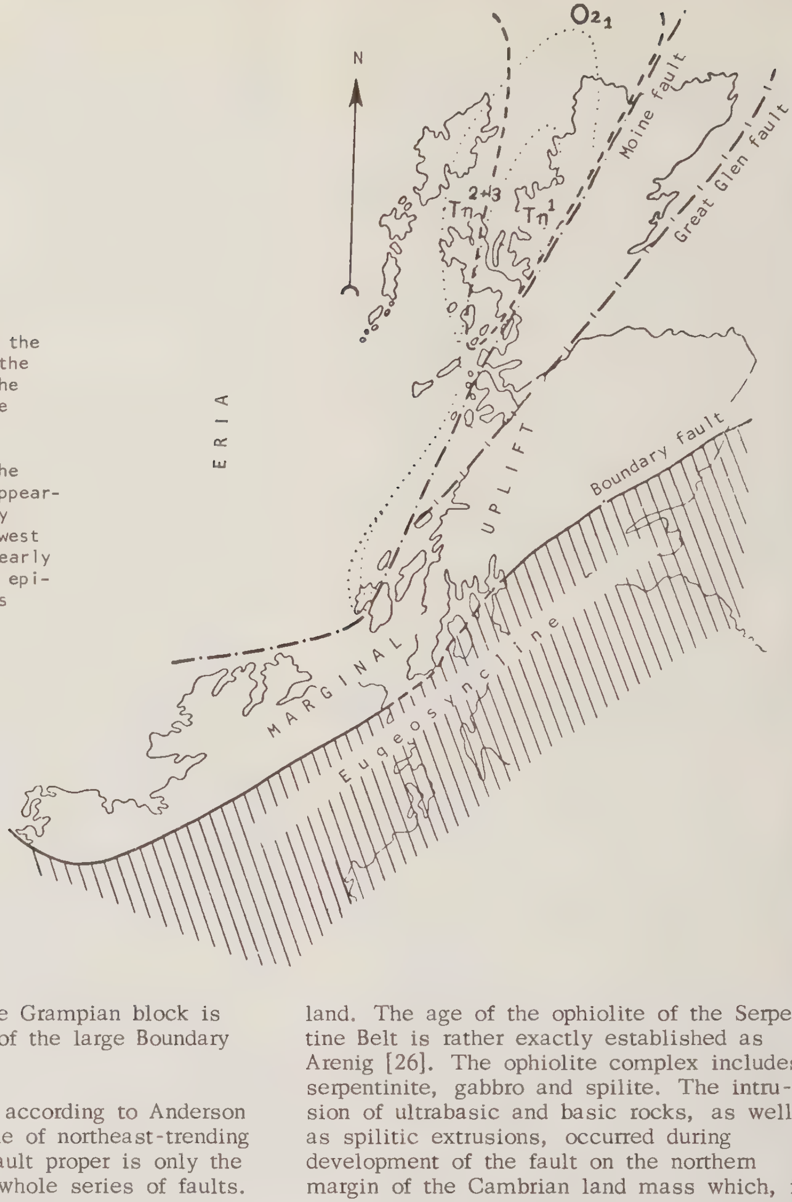

Fig. 5. Relation of the Eria platform to the eugosyncline at the beginning of the Ordovician.

Further growth of the marginal uplifts; appearance of the Boundary fault; in the northwest an embayment of an early Ordovician shallow, epicontinental basin is shown (Or_1).

In the southeast, the Grampian block is delimited by the zone of the large Boundary fault.

The Boundary fault, according to Anderson [26], is a complex zone of northeast-trending faults. The Boundary fault proper is only the southeasternmost of a whole series of faults. Southeast of it lie Downtonian and Lower Devonian rocks; to the northwest lies the Serpentine Belt, or where it is absent, the upper Dalradian (Cambrian) and Ordovician rocks. The Serpentine Belt, as shown by Jehu and Campbell [35], is bounded in the northwest by a large serpentine fault. The Boundary fault zone contains other faults of secondary importance (the Northern Esk fault, the faults of Loch Tay type).

The Serpentine Belt related to the Boundary fault zone can be traced across Scotland from Stonehaven to Bute Island over a distance of 225 km, and it probably continues farther west across the northern end of Ireland. The age of the ophiolite of the Serpentine Belt is rather exactly established as Arenig [26]. The ophiolite complex includes serpentinite, gabbro and spilite. The intrusion of ultrabasic and basic rocks, as well as spilitic extrusions, occurred during development of the fault on the northern margin of the Cambrian land mass which, it is believed, existed on the site of the present Central Lowlands and the Southern Uplands of Scotland. During the Cambrian this hypothetical land mass served as a barrier separating the marine basin of northwestern Scotland with its American fauna from the basin of England and Wales [26].

The folded structures on the northwestern side of the Boundary fault, which involve the Dalradian and Lower Ordovician strata, were formed [26] during the main stage of Caledonian folding (post-Middle Ordovician but pre-Downtonian). According to R. Shackleton [62] and M. Stone [47] these structures are very complex. The Boundary fault itself

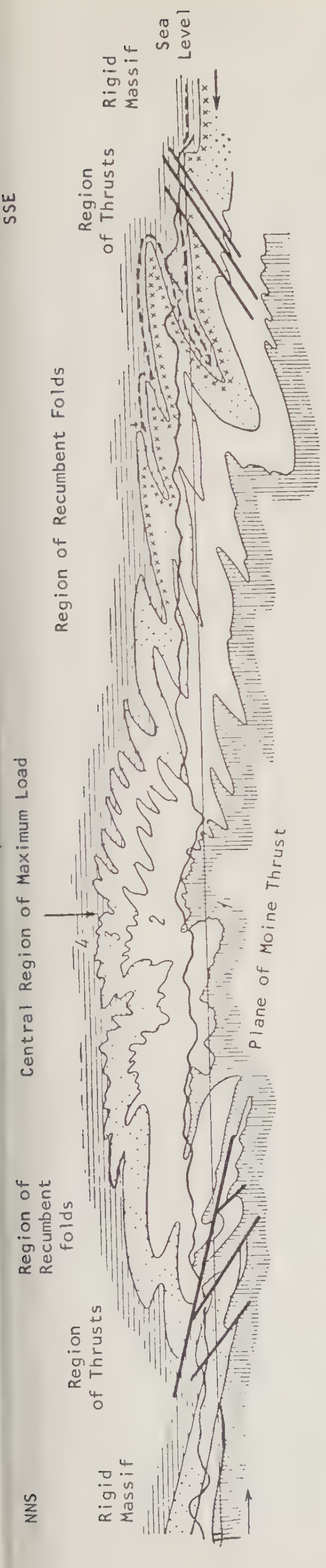

Fig. 6. A schematic section through the Northern Scottish Highlands (after B. Peach [54]).

1 -- Lewisian; 2 -- Torridonian; (=Moine); 3 -- Cambrian (Dalradian); 4 -- Ordovician.

came into existence after the Early Devonian time. The other members of the Boundary fault zone may be a little older (pre-Early Devonian).

I believe that in light of all this the Boundary fault, which in Arenig time became a zone of penetration for ultrabasic and basic magmas, must have played the role of a boundary dislocation which separated the Cambrian Grampian eugeosyncline from the blocks of the Central Lowlands and the Southern Uplands. We have seen that the Ordovician section on the southern margin of the Grampian Highlands is very incomplete, that it is represented there by the relatively thin Arenig deposits (siliceous volcanics) and by the terrigenous Caradoc formation. Older local rocks such as the black siliceous shale of Arenig age are volumetrically important among the clastic materials of the Caradoc formation ([26], p. 486). Unlike the southeastern boundary of the Grampian Highlands, the Southern Uplands have a very thick and complete eugeosynclinal Ordovician and Silurian section [34]. In the Central Lowlands near Stonehaven, southeast of the Boundary fault, the Lower Devonian is underlain by an Upper Silurian (Downtonian) series whose exposures have a thickness of 700 m ([26], p. 486). The Downtonian sediments are absent in the Grampians. The impression is created that in Ordovician and Silurian time the Grampian block was no longer an area of geosynclinal sedimentation (Fig. 5), although geosynclinal sedimentation continued during that time farther southeast within the Lowlands and in more southerly regions of Scotland. In the Central Lowlands the Ordovician, Silurian and probably Cambrian section must differ from the Grampian Highlands section in thickness and completeness. There is no need to consider the Lowlands region as a hypothetical land barrier which during the Cambrian separated the marine epicontinental basin of northwestern Scotland with its distinctive "American" fauna from the Cambrian basin of England and Wales. As we have seen, it is the Northern Highlands block that served as a barrier. The Central Lowlands and the Southern Uplands were the only regions of Scotland in which apparently geosynclinal sedimentation persisted until the end of the Lower Paleozoic. This, very likely, is the reason why the post-Caledonian "posthumous" movements occurred here with the greatest intensity and completeness and why the Devonian section is so thick, complete and varied.

Passing, in conclusion, to the general view of the geologic history of Scotland during the Precambrian and Early Paleozoic, let us discuss the synthesis proposed by Peach [42]. His work reflects in its entirety the

classical concept of the Scottish Caledonides. In Peach's opinion all the highlands are composed of Lewisian, Torridonian (Moine), Cambrian (almost all Dalradian) and Ordovician (including certain Dalradian formations) rocks. In the north-northwest (Eria) and the south-southeast (Central Lowlands) lay rigid massifs whose movement towards each other produced the folded structure of the Northern and Grampian Highlands. Thrust systems developed on the margins of the rigid massifs (Moine Thrust in the north, the Boundary fault in the south). The concept of the Caledonian structure is reduced by Peach to a vast fan-like anticlinorium whose southeastern and northwestern limbs are characterized by the development of recumbent folds (Fig. 6).

Peach postulated the stratigraphic equivalence of the Moine and Torridonian series, the post-Cambrian age of the foliation in the Moine and Dalradian rocks and the intense, geosynclinal sedimentation in the Northern and Grampian Highlands during a great interval of time from the Lewisian through the Ordovician. Besides this, Peach used certain stratigraphic details. He correlated the basic lavas (Taywellach?) of the Upper Pelitic and carbonate formations of the Dalradian (Cambrian) with Arenig spilite and the Loch Tay limestone of the same formation with the Margee limestone of the upper part of the Cambrian Upper Psammitic formation, etc.

Unfortunately, Peach's brilliant conceptions are not confirmed by the mass of observations

Fig. 7. The relation between the Eria platform the Caledonian folded zone and the Devonian zeugogeosyncline.

Horizontal shading -- Eria platform; vertical shading -- Caledonian folded zone; large dots -- Devonian zeugogeosyncline.

The Great Glen rift is shown (tentatively) as Middle Devonian. The abyssal Moine fault becomes the Moine thrust (before Middle Devonian).

accumulated by British geologists in the course of the very interesting attempts at correlation of the ancient rocks of Scotland, Ireland, and Scandinavia undertaken by Holtedahl, Polkanov and Anderson. We have seen that the Scottish Highlands cannot be included in the classical Caledonide belt. During Precambrian and Cambrian time, Scotland was gradually broken up by faults into a series of blocks which were depressed successively like piano keys, regulating the boundaries of the geosynclinal zones and the character and duration of their development. The Moine geosyncline, according to all evidence, had its greatest extent southeast of the Eria platform bounded by the ancient Moine abyssal fault. In the beginning of the Dalradian (Riphaean, upper Sparagmite) the newly formed Great Glen abyssal fault cut the region of the Northern Highlands from the Moine miogeosyncline, converting it into a marginal uplift. The effect of the movements on the Great Glen fault was to change the Moinian miogeosynclinal regime of the Grampian region into a eugeosynclinal regime which persisted through the Cambrian period. Finally, at the beginning of the Ordovician, the new abyssal Boundary fault came into existence and cut off an area of the Cambrian eugeosyncline, the region of the Central Lowlands and the Southern Uplands. At the beginning of the Ordovician, the Grampian Highlands became a marginal uplift but the eugeosynclinal regime continued to exist in the south, in the Central Lowlands, and in the Southern Uplands until the end of the Silurian.

From the Middle Ordovician and the entire system of blocks, with the exception of the ancient Eria platform, was subjected to strong, spasmodic folding accompanied by various intrusions, and the sedimentary and volcanic rocks of the Moine, Dalradian and Arenig ages became foliated and were changed into schists. The waves of Caledonian folding reached the southeastern edge of the Eria platform through the Grampian and the Northern Highlands blocks and changed the structure of the ancient Moine fault into a complex system of overthrusts overlapping the edges of the platform.

During the Devonian (Fig. 7), a vast zeugogeosyncline developed on the newly-formed, heterogeneous epi-Caldeonian platform, most of which lay within the present North Sea and the adjacent Atlantic Ocean. Individual "apophyses" of this zeugogeosyncline extended into Scotland in the form of synclines and intermont basins in whose development the Great Glen and Boundary abyssal faults played a decisive role.

Further study of the system of abyssal faults of different ages, the Moine, Great Glen and Boundary faults, which unite into a bundle and penetrate into the body of the Eria platform near the northern end of Ireland, would be of exceptional interest. The northern part of the British Isles, which has been very well investigated in the past and continues to be thoroughly studied with unfailing energy and in increasing detail, is one of the few areas on the earth where a thorough knowledge may be obtained of the spatial and genetic relations of the processes of origin and development of abyssal faults, folding, magmatic activity and metamorphism.

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TIME-ROCK SUBDIVISION AND THE CONDITIONS OF DEPOSITION OF PERMIAN AND LOWER TRIASSIC SEDIMENTS OF THE VERKHOYANSK RANGE

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1. STRATIGRAPHIC SUBDIVISION OF THE PERMIAN AND LOWER TRIASSIC OF THE VERKHOYANSK REGION

The scheme of stratigraphic subdivision and correlation of the Permian and Lower Triassic deposits of the Verkhoyansk Range presented here was compiled on the basis of the author's own work and the data collected by a large group of geologists of different organizations (the Dal'stroy Geologic Exploration Office, the Yakutian Affiliate of the Academy of Sciences, the Yakutian Drilling Office, the Arctic Geologic Research Institute, the All-Union Geologic Research Institute, and other organizations) who have done mapping and special geologic work in the region. During 1951-1955, the author's lithologic and petrographic work was concentrated in the latitudinal section and southern part of the central section of the Verkhoyansk Range. A detailed study of type sections in the folded belt of the western slope was made along a number of right-hand tributaries of the Aldan and Lena Rivers and the route was mapped at a scale of 1:200,000. In 1955, the northernmost section on the left bank of the Lena near Cape Chekurov was also investigated.

The petrographic study of the type sections, the identification of fossils and correlation with sections studied by other investigators (V.N. Andrianov, A.S. Kashirtsev, A.V. Vikhert, in the latitudinal area, and A.V. Zimkin, A.V. Leiptsig, G.S. Borushko, V.M. Mel'nikov, and others, in the central area) made it possible to compile a standard Permian and Lower Triassic section, It became possible also to correlate this sequence with the more northerly sections of the meridional area of the Verkhoyansk Range previously studied by workers of the Arctic Geologic Research Institute, A.P. Atlasov, A.A. Mezhvilk and others, and recently refined by detailed investigations and large-scale mapping conducted by the workers of the same Institute under V.M. Lazurkin's supervision.

Within the Verkhoyansk Range, the Upper Paleozoic cycle P_1 -- T_2 can be subdivided into a number of complexes or formations which represent stable paragenetic assemblages of facies traceable laterally and vertically and characterizing definite physical and geographic stages in the development of the cycle. These complexes are: 1) the lower sand and shale transgressive complex (P_1^{1+2} -- $C_3^?$) formed during the course of the main transgressive stage of the cycle; 2) the shale complex (P_1^3) characterizing the stage of maximum transgression and the "stillstand" of the basin; 3) the flysch complex (P_2^1) of the early stage of general regression; 4) the coal-bearing complex (P_2^2) corresponding to the sharp diminution of the marine basin and the appearance of coal-bearing sediments in some areas of the Verkhoyansk region; and 5) the redbed lagoonal-deltaic complex (T_1) characterizing the final stage of the cycle. After the deposition of the sediments of this cycle a large part of the western Verkhoyansk region was regionally uplifted. In some small areas of the region, continental sands which may be regarded as a separate formation (T_2) were deposited at this time.

It should be emphasized that the sections of each of these complexes are strictly synchronous and the complexes are therefore definite stratigraphic or time-rock units. This is proved by the fact that all fossils found up to now in the Permian and Lower Triassic rocks of different parts of the Verkhoyansk Range and determined by different investigators (A.S. Kashirtsev, E.M. Lyutkevich, A.V. Zimkin, Yu. N. Popov, A.F. Yefimova, I.I. Tuchkov, V.N. Andrianov, B.S. Abramov, A.V. Vikhert and V.D. Shutov) belong to strictly defined horizons. The necessary paleontologic analysis was performed by A.S. Kashirtsev, who proposed a general biostratigraphic subdivision of the Permian, and by Yu. N. Popov, who worked out an analogous scheme for the Triassic of the Verkhoyansk region [9, 17]. However, because of the relative scarcity of fossils and the presence among them of a large number of endemic forms, especially in the

Permian strata, it is necessary in working out subdivisions and correlations to stress the petrologic and facies characteristics of the rocks, checking and correcting these by paleontologic evidence.

Within the folded zone of the Verkhoyansk Range three areas may be distinguished by differences in the character of the sections: 1) the latitudinal area extending parallel to the northern slope of the Aldan Shield (Tompo-Tumara interfluve), 2) the central area adjacent to the Viluy depression proper (Tumara-Sobopol interfluve), and 3) the meridional section bordering the eastern slope of the Anabar massif and including the Verkhoyansk Range known as the Kharaulakh Mountains and the Orulgan Range (Atlasov's Upper Verkhoyansk Range).

The lower sandstone-shale complex is separable everywhere in the Verkhoyansk Range into two sequences partly corresponding to the Sakmarian and Artinskian stages. The lower sequence in the latitudinal section was separated by us and termed the Tolchansk series. Its equivalents in the central section are the Solonchansk and Imtanzhinsk formations named by N.P. Kheraskov and in the meridional section, A.A. Mezhvilk's Tiksinsk formation.

The lower sequence is composed mainly of black shales which are strongly phyllitized in the latitudinal and meridional sections. The individual units of the sequence consist of frequently alternating, thin-bedded siltstone and shale and resemble the flysch type of interbedding. At the juncture of the latitudinal and meridional sections, thick beds of sandstone containing lenses of carbonaceous shale filled with plant imprints appear in the upper part of the sequence. This sequence lies unconformably on the Carboniferous and Devonian strata. The character of the contact can be seen clearly only in the northern Kharaulakh region and in the Setta-Dabansk anticlinorium.

The fossil fauna of the sequence varies considerably from one area to another. The rocks of the meridional section contain many brachiopods, Productus grunwaldti, P. crisatotuberculatus, Spirifer strangwaysi and other forms which greatly resemble the Sakhmarian species of the Urals. The strata of the latitudinal and central sections of the Verkhoyansk Range have a very scant and poorly-preserved brachiopod and pelecypod fauna. The characteristic feature of the fauna in this sequence is the absence of Productus verhoyanicus, the index fossil of the Artinskian stage. On the assumption that it lies below the Artinskian beds bearing Productus verhoyanicus, this sequence is referred to the Sakmarian stage. The correlation of the sections is shown in Fig. 1.

In the central section, the upper sequence of the sand-silt complex was named the Kygyltass formation by Kheraskov. In the latitudinal section it is substantially different and is known as the Berandinsk formation. Contemporaneous deposits in the meridional section are represented by the lower part of the Verkhoyansk formation and in the Orulgan Range by the essentially sandy, fourth formation of Atlasov (Fig. 1). The sequence as a whole has a coarsely graded structure and consists of thick (5-10 to 30 to 50 m) shale-siltstone beds alternating with equally thick sandstone beds.

The metamorphic changes in these rocks (shale and sandstone) are similar to those in the underlying beds. The sandstone and shale of the latitudinal zone are the most strongly compacted and phyllitized. The sequence has the greatest thickness in the latitudinal section and the southern part of the meridional section, and it is here also that the thickest groups of sandstone beds (up to 50 m) occur which higher in the section change into gravelly beds and pebble conglomerate. The amount of sandy material and its grain size diminish sharply toward the eastern slope of the range.

The Kygyltass formation and its analogues are characterized by an abundance of fossils. Among the index fossils are Productus verhoyanicus, P. cancriniformis, P. aagardi, P. lutkewitschi, P. kharaulakhensis, Spirifer nitiensiformis, Spiriferella saranae and many others. Carbonaceous shale with plant imprints (Noeggerathiopsis theodori, Paracalamites sp., etc.) are sometimes found among the gravel and sandstone conglomerate of the upper part of the formation. On the basis of their fossil assemblage these sediments are of the Artinskian age.

The thickest part of the sand-silt complex coincides with the axial zone of the modern Verkhoyansk Range, amounting to 4500 m in the meridional section and over 3500 m in the latitudinal section.

The overlying shale complex is possibly equivalent to the upper Artinskian and all of the Kungurian stages. In the latitudinal and central sections of the Verkhoyansk Range this complex is fully represented by the Echiysk formation, which is traceable, according to the geologists of the Yakutian Drilling Office and the Dal'stroy as well as the author's own observations, from the Sobopol River to the Tompo River (Fig. 1). In the meridional section, the analogue of the Echiysk formation is the upper half of Mezhvilk's Verkhoyansk formation which lies transgressively on the Lower and Middle

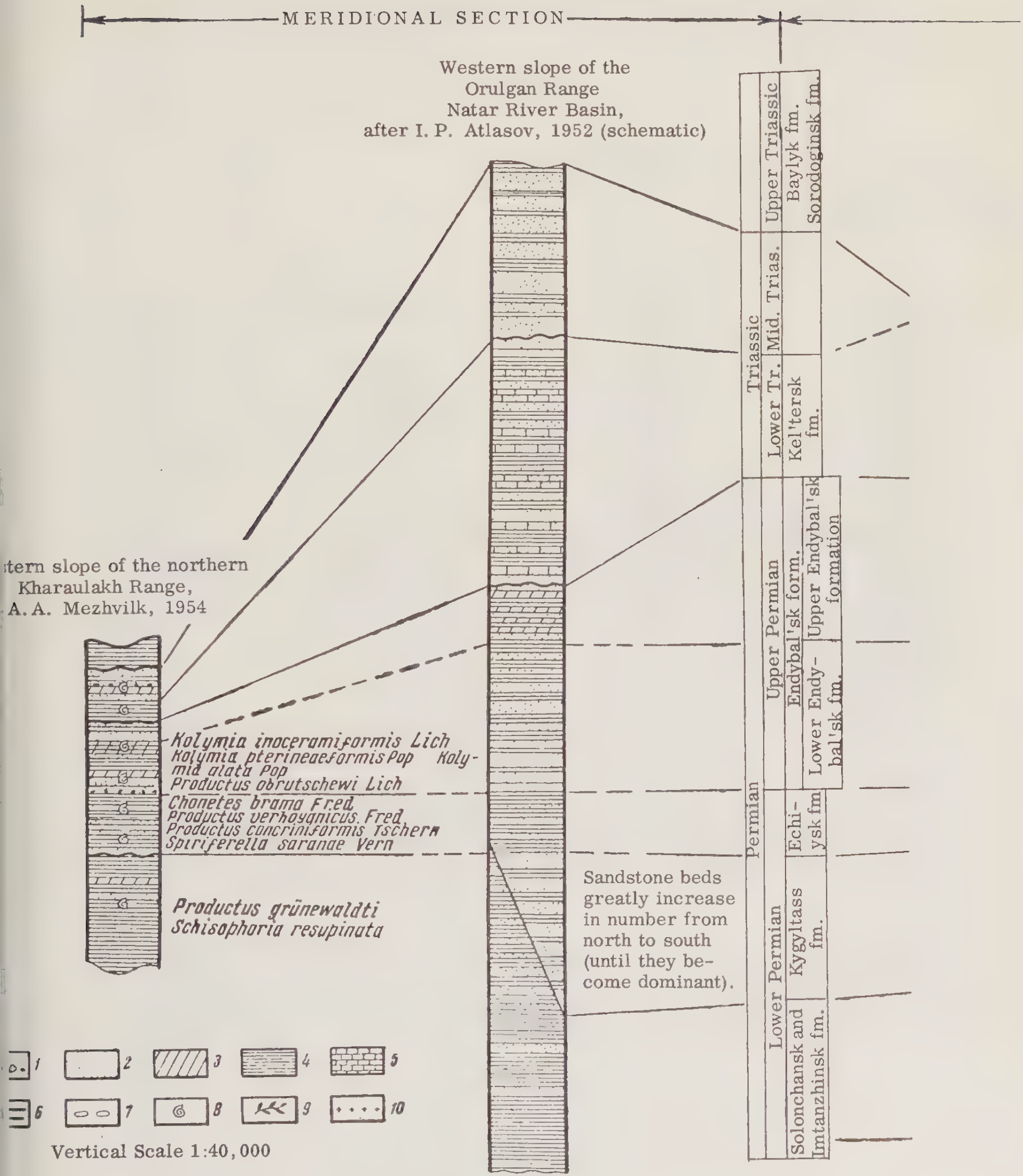
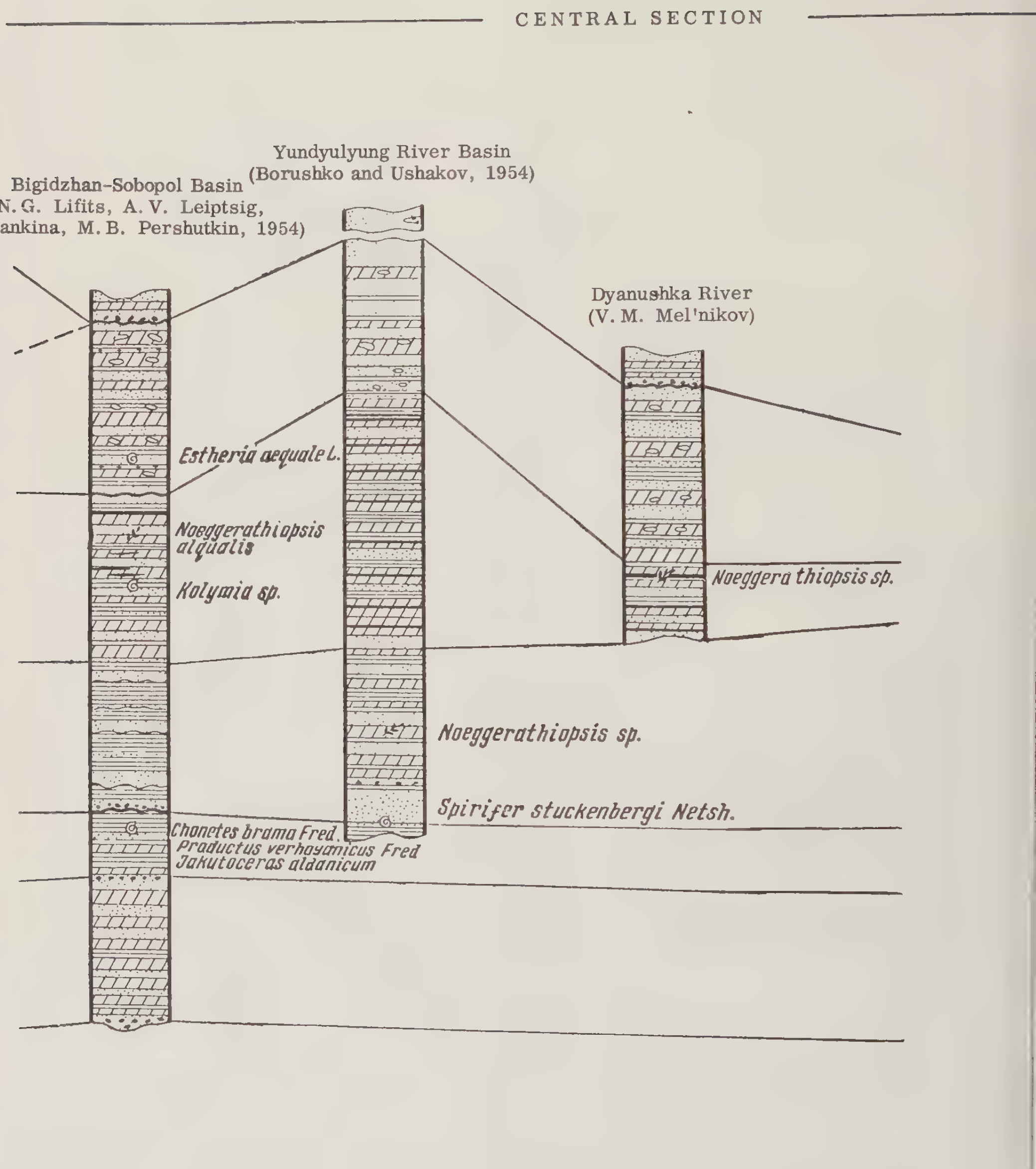


Fig. 1. Correlation of Permian and Lower Triassic Deposits of the Verkhoyansk Region.

1-gravel and conglomerate; 2-sandstone; 3-siltstone; 4-argillite, shale and silty shale; 5-limestone; 6-coal; 7-carbonate concretions; 8-fossil occurrences; 9-plant fossil occurrences; 10-diabase.



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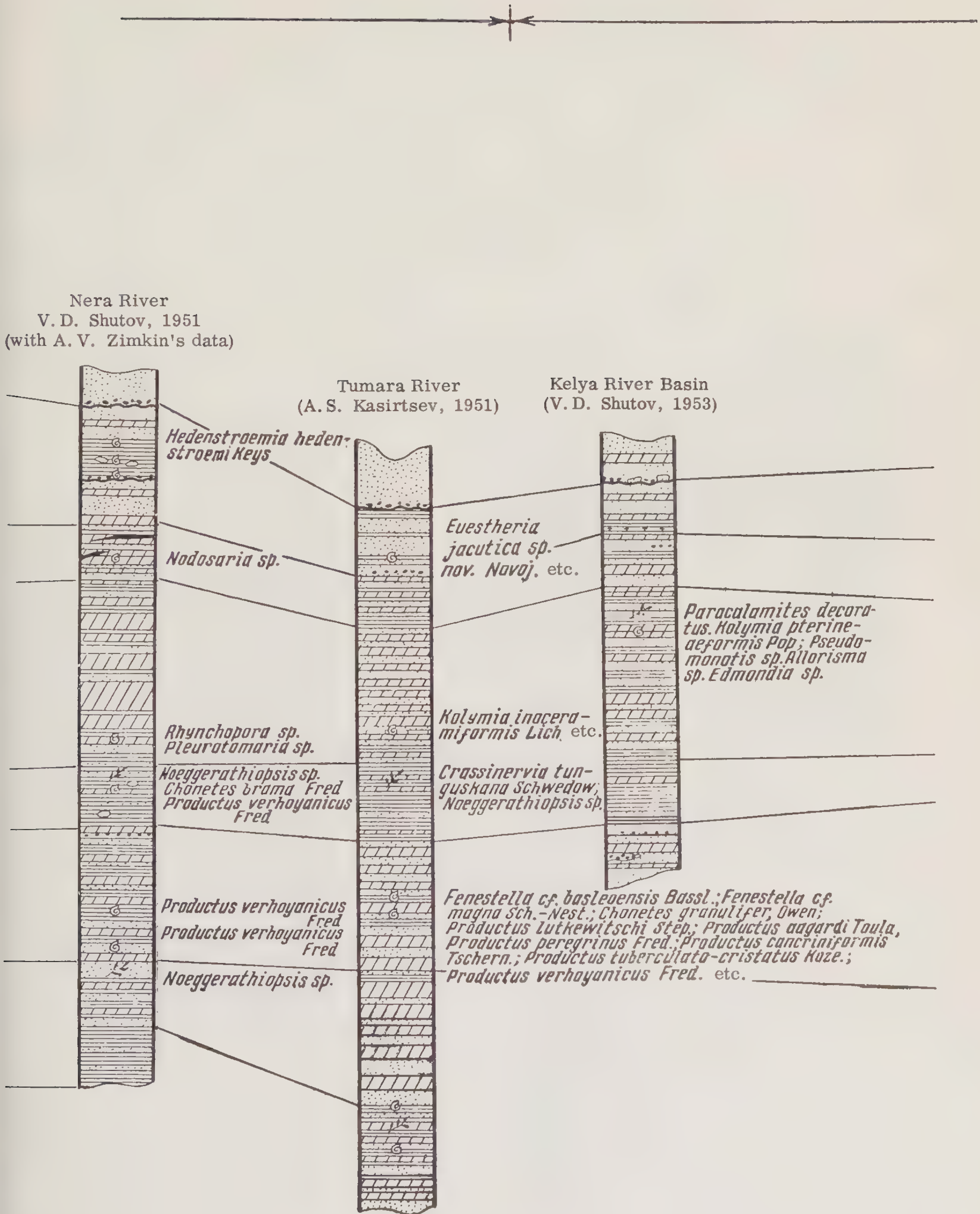

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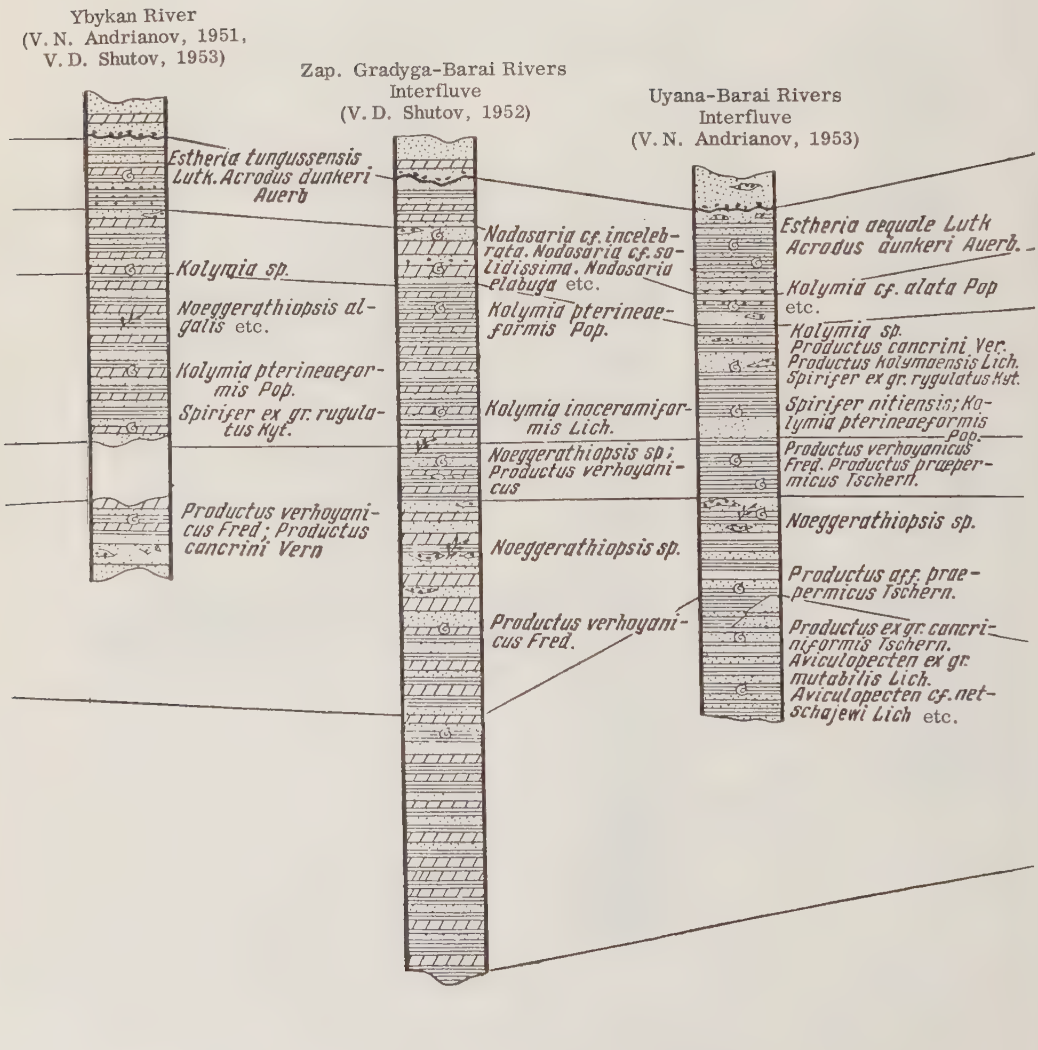
LATITUDINAL SECTION



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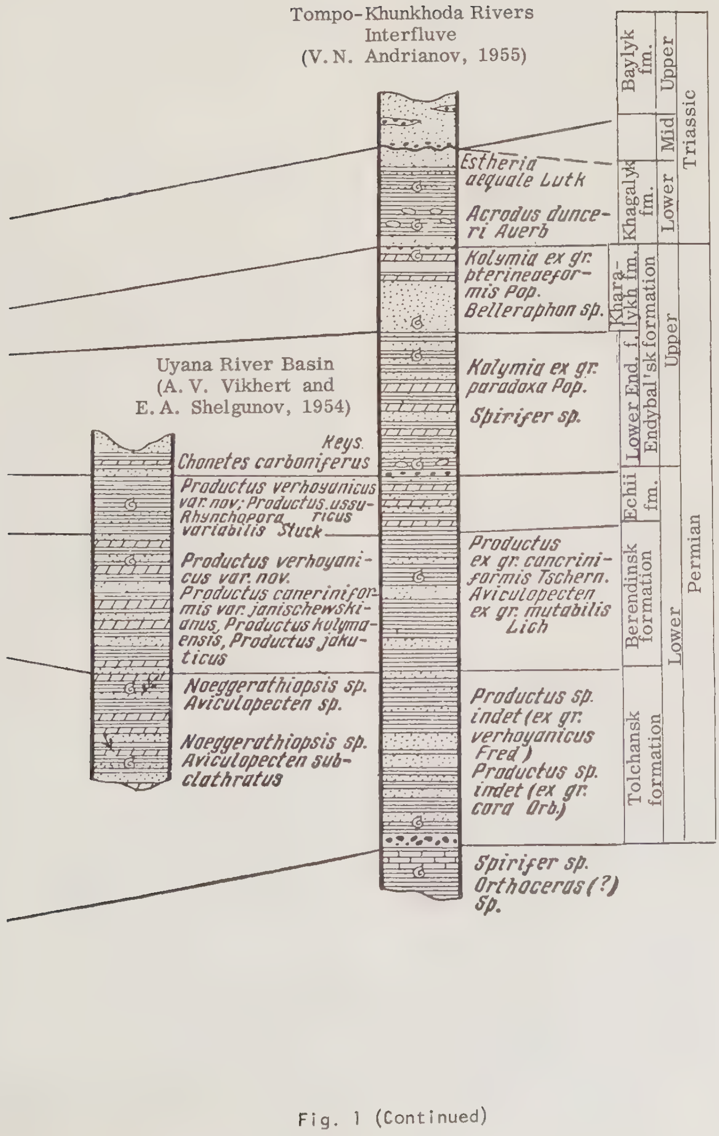

Fig. 1 (Continued)

Paleozoic rocks of the western slope. The Echii formation and the upper beds of the Verkhoyansk formation are exceptionally homogeneous and are composed of black shale containing much finely macerated plant debris. Large siderite concretions are present almost everywhere in the black shale. On the western periphery of the meridional and latitudinal sections of the Verkhoyansk Range in the basins of the Bigidzhan and Tompo Rivers, the Echii formation and its analogues contain sandstone beds with pebbles and occasional, poorly-rounded boulders of Paleozoic limestones.

The shale contains a brachiopod fauna nearly identical to that of the underlying complex and distinguishable only by the presence in it of specific varieties of Productus verhoyanicus, as determined by Kashirtsev [8]. Along the trend of the western slope of the Verkhoyansk Range, the shale complex is markedly uniform in thickness (400 to 500 m), but transverse to the trend the thickness of the complex increases in jumps, reaching 1500 m directly east of the present divide.

The flysch-like complex which overlies the shale complex corresponds to the Lower Endybal'sk formation of the western Verkhoyansk Range and to the lower parts of the Kharaulakh formation of the meridional section. These beds are considered to be of Kazanian age although this dating is probably not precise, especially so far as the upper beds are concerned. The contact of this formation with the underlying shale complex is generally gradational, but this is not true of the entire Verkhoyansk region. In some areas, for example, at Baray in the latitudinal section and in the basin of the Bigidzhan River in the central section, there is a notable unconformity between it and the underlying shale.

The Lower Endybal'sk formation and the lower beds of the Kharaulakh formation are composed of thick (up to 300 m) flysch-like groups of beds infrequently separated by beds or groups of beds of sandstone (up to 50 m). The flysch-like groups consist of rhythmically alternating silt-clay and sand layers ranging in thickness from 0.3 to 3.0 m. Toward the eastern slope of the Verkhoyansk Range, the Lower Endybal'sk formation loses its characteristic graded bedding and the number of sandy beds in it diminishes.

The entire complex is rather clearly characterized by its fossil content. It contains Kazanian spiriferids (Spirifer stuckenbergi, S. ex. gr. ruqulatus, S. keyserlingi) and a number of species of Kolymia (Kolymia inoceramiformis, K. pterineaeformis, K. alta and others). Some productids are also present among the index fossils, for example, Productus obrutschewi.

The thickness of the complex reaches 1400 m on both sides of the range. The greatest thickness is in the central section of the Verkhoyansk Range. The present divide is marked by a zone where a sharply diminished section resulted from the rise of the cordillera.

The Permian section is topped by sandy-shale beds which in the central section of the Verkhoyansk Range contain a series of coal beds (with maximum thickness of 2 m). This sequence is separated as a coal-bearing complex and corresponds to the coal-bearing Upper Endybal'sk (Nersk) formation of the central section and to its barren analogues of the latitudinal (the Khoralyg formation) and meridional sections (Atlasov's third formation of the Orulgan Range and the upper part of the Kharaulakh formation in the Kharaulakh Mountains, which contains a large gastropod fauna (Fig. 1).

A valuable aid in drawing the lower boundary of the complex in the latitudinal and central sections of the Verkhoyansk Range is provided by the appearance of garnet, a mineral which is completely absent from the rocks of the underlying sediments. Because of the lack of space in this paper for a detailed description of the lithology of the Permian coal-bearing formation, we shall mention only that it has many facies and that its thickness is variable. In the central section of the Verkhoyansk Range, the thickness of the Lower Endybal'sk (Nersk) formation is greater than 1500 m in the central areas and decreases to 400 in the north and northeast. The formation has well-developed cyclic features. The thickness of the cyclothems ranges from 5 to 30 m. Marine and littoral facies alternate regularly with lagoonal-continental sediments.

In the latitudinal and meridional sections, the analogues of the coal-bearing formation are littoral and in part alluvial facies of reduced thickness (150 to 400 m). The cyclic nature of the section changes to a monotonous alternation of thick (150 m) groups of sandstone and siltstone beds. In the siltstone, especially in the southeastern regions of the Verkhoyansk Range, there are lenses of pebble conglomerate. Towards the central section of the range in the basins of the Kel' and Natar Rivers, the uniform groups of sandstone beds break up into thinner groups separated by carbonaceous shale with plant imprints.

The coal-bearing complex of the eastern slope of the Verkhoyansk Range has been very little studied up to the present time. According to the data of the Dal'stroy

geologists (A.V. Zimkin, P.N. Ushakov and others) and of A.S. Kashirtsev and A.V. Vikhert of the Yakutian Affiliate of the Acad. Sci. U.S.S.R., the Permian section of the eastern slope terminates in a thick group of predominantly sandy beds termed the Billyakh formation by A.V. Zimkin.

This formation is present along most of the eastern slope from the vicinity of Verkhoyansk to the basin of the Tompo River. Last year, I.V. Polubotko, a Dal'stroi geologist, showed that some Lower Triassic formations were erroneously included in the Billyakh formation in the basin of the Echiy River. Polubotko recognized a Permian formation, the "Molodobsk" formation, correlative on the basis of its fauna with the Upper Endybal'sk and Khoralyg formations of the western slope. The relation of the Billyakh formation of other regions with the new Molodobsk formation is not yet certain.

The fossil faunal and floral characteristics of the coal-bearing complex are not sufficiently clear. Very many forms, widely distributed in the lower Upper Permian beds, are also present in the upper part of the section. There are, however, several characteristic pelecypods and gastropods, e.g., (Bellarophon imtatschanensis, Myonia valida nov. sp., Pecten nov. sp., Alloricha nov. sp.), and further study will, in Kashirtsev's opinion, uncover index fossils among them [9]. The plant remains are analogous to those found in the lower part of the Upper Permian, i.e., Noeggerathiopsis sequalis, etc.

Above the coal-bearing complex the Lower Triassic is represented by sedimentary beds of many facies which we separate as a continental redbeds complex. In the central area it is represented by the Kel'tersk redbeds with Hedenstnemia hedenstremy Kays; these beds are replaced in the latitudinal section by gray sediments of the Khagalyk formation containing Estheria (Estheria sequale) and sharks' teeth (Acrodus dunkeri). In the meridional section of the Verkhoyansk Range, the Upper Triassic is composed of marine, mainly argillaceous sediments with subordinate limestone beds (in the Orulgan Range). The abundant fauna permits separation of two stages, Indskian and Olenekian, with further subdivision into faunal zones [17]. In the more southerly regions only the Indskian stage has been recognized, although some higher beds are possibly present.

Numerous diabase sills at different stratigraphic levels (the sills range in thickness from 10 to 30 m) are the most notable feature of the Lower Triassic sediments of the western slope of the range.

The Lower Triassic deposits of the eastern slope are mostly shale with a normal marine fauna.

The maximum thickness of the complex is present in the central and southern parts of the meridional section (up to 1300 m); in the north and south it decreases to 200 m.

The Lower Triassic redbeds complex terminates the section of the Upper Paleozoic cycle. A large interruption in sedimentation in the Middle Triassic is now traceable through almost all of the latitudinal and central sections of the Verkhoyansk Range. The shoreline of the Middle Triassic basin shifted farther east and northeast. In some of the regions of the western slope, local downwarps were formed in which thin sandy continental sediments accumulated contemporaneously with the general block uplifts accompanied by large-scale faulting and intrusions of diabase. The thin sandstone series containing sporadic beds of clayey coal, described by V.P. Andrianov from the basin of the Uyana and Tompo Rivers, originated by this type of sedimentation. The stratigraphic position of this thin series (up to 300 m thick) between the fossiliferous Lower Triassic beds and the basal layers of the Baylyk formation (J_1^1 -- T_3^{ar}) and the few occurrences in it of Middle Triassic spores enabled Andrianov to assign it to the Middle Triassic. We have placed this problematic series in a separate arenaceous, continental complex which more clearly reflects the occurrence of local downwarping against the background of general block uplifts. A detailed study of the complex is a project for the future.

The Middle Triassic deposits are most fully represented in the meridional area of the Verkhoyansk Range, where the marine regime persisted without change throughout almost all of the Mesozoic era.

2. PERMIAN AND LOWER TRIASSIC ENVIRONMENTS OF SEDIMENTATION IN THE VERKHOYANSK RANGE

THE EARLY PERMIAN EPOCH

The time of accumulation of the lower, arenaceous shale complex (Tolchansk series-Kygyltass formation). At this time the Verkhoyansk Range was the marginal zone of a large marine basin extending far to the east and bordered on the west by the low shores of the East Siberian land mass. The boundary of the marine basin passed east of the lower course of the Lena and Aldan Rivers, and possibly extended to the west in the vicinity of the mouth of the Viluy River into the region of the Lena-Viluy depression. The sediments of the lower,

sandy shale complex were deposited during the Early Permian transgression in two stages, during which the present Tolchansk and the Kygyltass formations were formed.

During Tolchansk time, thin clay sediments were laid down unconformably on different Lower and Middle Paleozoic beds throughout the territory of the Verkhoyansk Range. It should be noted that the advance of the sea was not accompanied by the deposition of basal conglomerates, which indicates that the inundated portions of the land had been highly eroded. At the end of Tolchansk time, a short marine regression took place, causing an intensified deposition of detrital material in the basin, represented now by a broad belt of sand of the shore dune, spit and bar facies along the boundary of the latitudinal section (Nera and Baraya Rivers). Locally, lagoonal facies represented by thin argillaceous sediments with well-preserved plant imprints, in places passing into carbonaceous shale, appear among the nearshore deposits.

In Kygyltass time the sea was enlarged once more. Sand, silt and clay were deposited. The increasing amount of sandy sediments shows that the land was uplifted at an accelerating rate. At the end of Kygyltass time, the uplifts reached their maximum and the delivery of terrigenous material to the basin was sharply increased. Along the edges of the Aldan and Anabar massifs, which were uplifted the most, there appeared broad bands of littoral sand and conglomerate, largely of the stream-channel facies but in places of alluvial facies. To the east, the gravel and the coarse sandstone disappear and are replaced by fine-grained sandstone, siltstone and clay deposited farther from the shore. Fine-grained sediments are typical also of the central section (the Nera and Yunyulyung Rivers). The absence of the band of littoral deposits possibly is explained by the fact that in these regions the sea entered the Viluy depression as a gulf (Fig. 2).

The detrital material was delivered to the basin from the west from the side of the Siberian platform and mainly from the most strongly uplifted Aldan shield and Anabar massif. The character and composition of the clastics indicate that erosion was affecting metamorphosed sediments and siliceous pyroclastic beds of the ancient Precambrian basement. The surface of the land was subjected to relatively slight weathering and the basin received fine-grained material uniformly distributed over its entire area. This circumstance determined the uniformity of accessory-mineral associations in the sedimentary rocks and the existence of a single terrigenous mineralogic province throughout the entire western slope of the Verkhoyansk Range characterized by the leucoxene-apatite-tourmaline association. In Kygyltass time, there occurred a sharp mineralogic differentiation together with increase in coarse-grained sediments. From the uplifted Aldan shield the basin received a characteristic epidote-zoisite-garnet assemblage and the fine fraction became enriched in fragments of extrusive rocks. In the central and meridional sections the association typical of the Tolchansk series was preserved. Thus two terrigenous mineralogic provinces existed during Kygyltass time. Their presence is due, on the one hand, to the localization, in the latitudinal section, of sandy tongues of stream deposits with their specific mineralogic composition, and, on the other, to the possible existence of a submarine barrier at the juncture of the latitudinal and central sections. The existence of this "partition" is suggested not only by the difference in the mineralogic composition of the sediments but also, as first pointed out by Kashirtsev, by certain definite faunal associations in the basin.

The time of accumulation of the shale complex (Echiysk formation and its analogues). During Echiysk time the marine basin continued to expand and reached its maximum size.

The sea extended westward over the Lower Paleozoic and Precambrian rocks of the Olenek dome and southeastward over the Setta-Dabansk anticlinorium and the peripheral area of the Aldan shield. It is difficult to estimate the extent of the sea in the central section because of the absence of direct evidence. However, the fine-grained, almost exclusively shaly character of the Echiysk formation indicates a considerable distance from the western shoreline. The Echiysk marine basin undoubtedly extended into the central, most strongly downwarped area of the Viluy depression.

The shape of this large gulf may be outlined now only with the aid of geophysical data.

Magnetic and gravity anomaly maps clearly show two sharp tongues of low magnetic and gravity values which extend from the upper Verkhoyansk region into the Viluy depression and are due to the deep submergence of the ancient basement [14]. The northern tongue stretches from the region of the Lindya River, crosses the Tyung River above its sharp bend and merges in the west with the Markhinsk gravity anomaly. The southern tongue, known among geophysicists as the "Berdigistyakhskii Gulf", enters into the territory of the Viluy depression opposite the mouth of the Aldan River and can be traced to the west for a distance of 250 km. The maximum amount of subsidence of the ancient basement in these areas is nearly

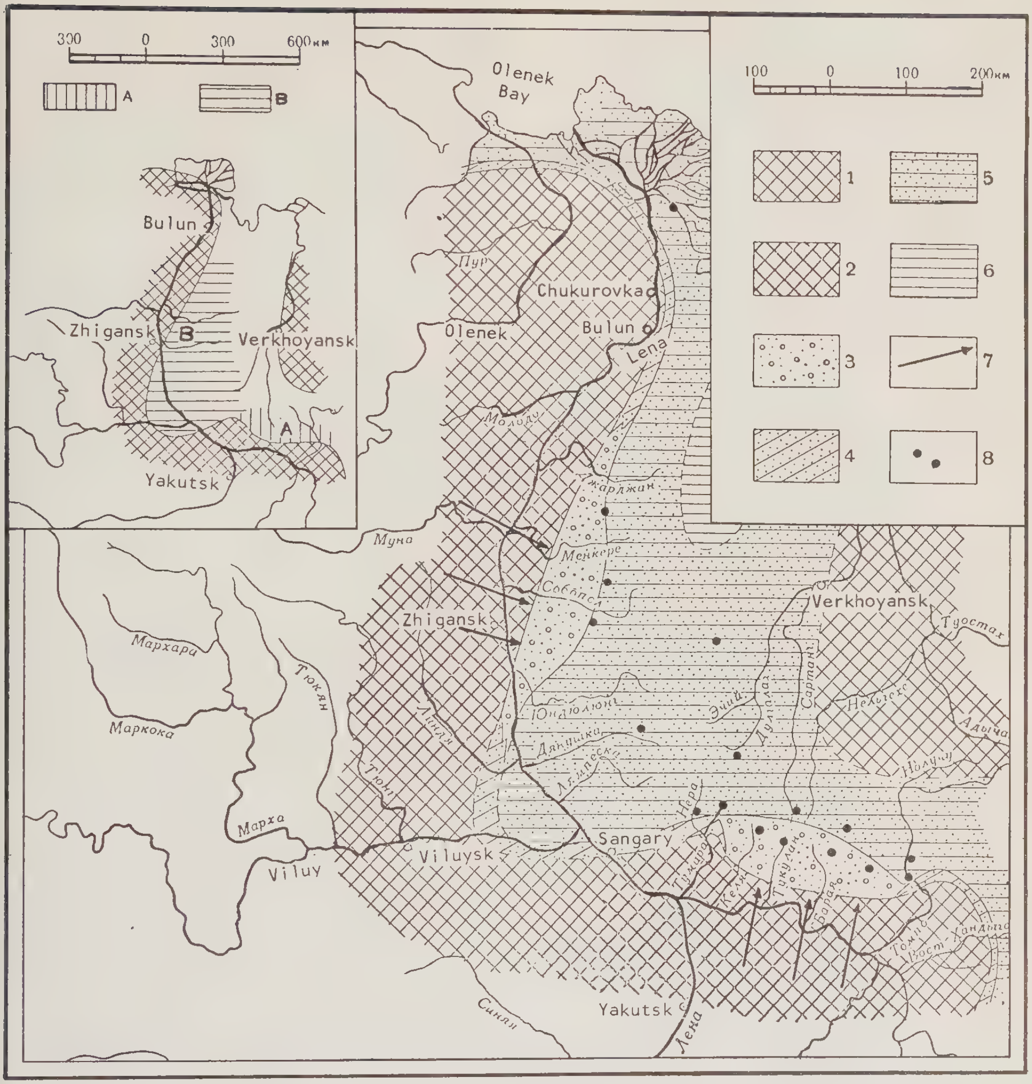

Fig. 2. Facies distribution in the Lower Permian basin at the end of the Kygyltass time.

1 - Weakly-dissected, lowered land areas; 2 - dissected, uplifted land areas; 3 - submarine deltaic deposits, mainly sand and silt with granules and pebbles; 4 - marine littoral sediments, mainly sand and silt; 5 - sediments of the relatively deep sea; 6 - mainly argillaceous sediments of the central areas of the sea; 7 - main direction of sediment transport; 8 - observation points.

Terrigenous mineralogic provinces: A - epidote-zoisite-garnet with allanite; B - leucoxene-zircon-tourmaline with apatite.

4500 m, and in the region of Vilyuysk, as much as 5000 m. The great thickness of the sedimentary cover indicates that Permian deposits of great areal distribution and including the Echiysk formation are present under the Mesozoic strata. Thus the contours of the anomalies are tentatively believed to indicate the limits of the maximum extension of the Lower Permian basin.

The sediments of the Echiy Sea are markedly uniform. Over the entire Verkhoyansk region, fine-grained, argillaceous sediments were deposited alternating very infrequently with sandy beds formed during short periods of increased delivery of detrital material (Fig. 3).

The littoral sediments have a limited distribution and are known from only a few areas nearest the ancient land mass. The fine-grained sandstone with occasional beds of gravelly material at the base are found along the slopes of the Anabar massif (in the

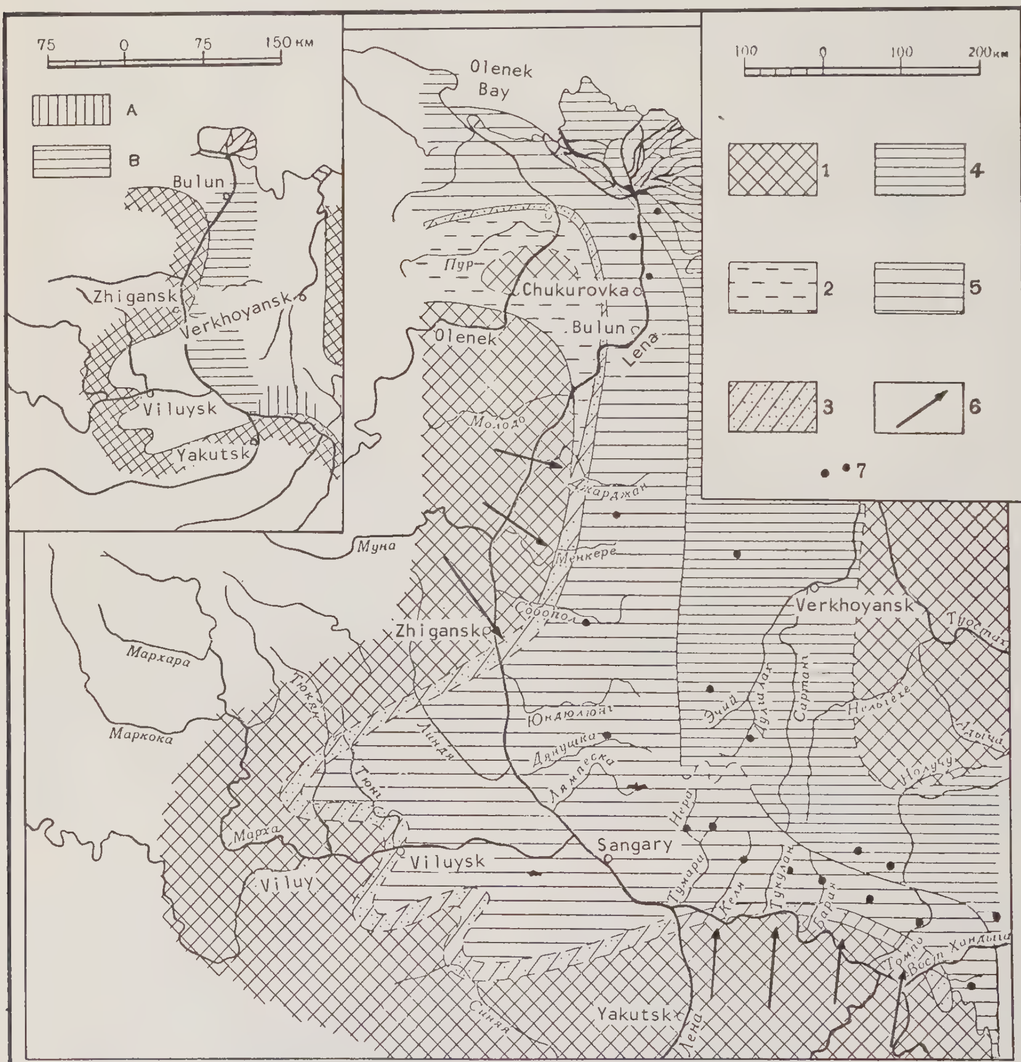

Fig. 3. Facies distribution in the Lower Permian basin in Echiysk time.

1 - land; 2 - gulf, lagoon and lake sand, silt and clay; 3 - marine littoral deposits, mainly sand and silt; 4 - thin deposit (up to 500 m) of marine clay; 5 - relatively deep-water marine clay (up to 1500 m); 6 - main directions of sediment transport; 7 - observation points.

Terrigenous mineralogic provinces: A - muscovite-chlorite-ilmenite with tourmaline; B - leucoxene-zircon-tourmaline with apatite.

middle course of the Bigidzhan River) and in the southeast Verkhoyansk region in the basin of the Tompo and Khunkhada Rivers. In the sandstone and shale of the southeastern areas, a number of investigators (Vikhert, Andrianov and others) noted the presence of large fragments and blocks of Cambrian and Silurian limestones derived from the erosion of island chains of the Setta-Dabansk anticlinorium. In the extreme north in the region of the Olenek uplift (Buator-Ayakit River, etc.), there are sandy and clayey sediments deposited on a low coastal plain periodically invaded by the sea. The zone of maximum downwarping in Echiy time lay in the region of the present northeastern limb of the Verkhoyansk Range. The thickness of the argillaceous sediments accumulated here reaches 1500 m. A much less intense downwarping occurred in the region of the western slope, where the sediments are only 400-500 m thick and are markedly uniform (Fig. 3). Further decrease in thickness should be expected in the west in the region of the Viluy depression.

Vikhert's data indicate that the boundary between zones of different intensity of subsidence passes through the latitudinal section of the Verkhoyansk Range approximately along the main divide [5]. In the central section this boundary shifts by jogs to the west and coincides with the crest of the large anticline near the divide. In the north, it lies along the strike of the Orulgansk anticlinorium.

The narrow zone of separation between regions with different regimes of subsidence marks, as it were, the axis of the future cordillera, whose appearance was to play a decisive role in facies distribution in the Upper Permian basin. The detrital material, as in the preceding epoch, was derived by erosion from the ancient rocks of the Aldan shield and Anabar massif, thus resulting in two terrigenous mineralogic provinces.

THE UPPER PERMIAN EPOCH

The time of accumulation of the flysch-like complex (Lower Endybal'sk formation and its analogues). The boundary between the Lower and Upper Permian marks an abrupt change in the history of the Permian basin. The transgressive development of the basin, which characterized the entire Early Permian, was succeeded by a general regression which reached its maximum at the end of the Late Permian and in the beginning of the Triassic. The shrinking of the basin and noticeable coarseness of sediments caused a decided change in the fauna. The predominantly brachiopod fauna of the Lower Permian was replaced by large thick-walled pelecypods of the Kolymia type, well adapted to live on a sandy bottom in strongly agitated waters. Among the brachiopods the productids diminished in importance and the spiriferids became widely distributed [8]. The uplifts initiated in Echiy in time in the axial zone of the Verkhoyansk meganticlinorium continued. During lower Endybal'sk time, the central submarine cordillera, was formed and affected the distribution of the facies.

The considerable coarsening of the sediments during this epoch indicates the beginning of uplift and the increased intensity of erosion on the western land mass which continued to supply the largest quantity of detrital material. The littoral, mainly sandy sediments are particularly widely distributed in the north (in the Tuor-Sis Range, the Bulkur River and Cape Chekurovsk regions), where they form a rather broad belt bordering the western edge of the basin. To the west, in the region of the present Olenek dome, which at that time was a low coastal plain, they are replaced by lacustrine and lagoonal deposits.

The zone of marine littoral sandstone stretches farther south along the eastern slope of the Anabar massif (Bigidzhan River) and is known also in the most southeastern areas adjacent to the Aldan shield (the Khinkhada and Tompo Rivers). It is probable that sediments of the same type, together with littoral-continental deposits of the chain of lagoons and coastal lakes, filled the shrunken Viluy gulf. The character of the supposed facies change in the littoral sediments on the low areas of the coastal plain of the Viluy gulf is probably analogous to the facies change which occurred in the north in the region of the Olenek dome.

East of the belts of littoral sandstone lies a broad region of finely-graded beds of the flysch type. The flysch zone was limited in the east by the central cordillera, but the deposits on the other wide of the cordillera were mainly clay without rhythmic stratification (Fig. 4). The flysch-like sediments of the western part of the narrow, trough-like Lower Endybal'sk basin were formed by small oscillatory movements of the basin of sedimentation and the main land area. It must be noted, however, that contribution of material from the cordillera, typical of flysch sedimentation, was not extensive here. As before, the main source of detrital material was the western land mass.

The time of accumulation of the complex of carbonaceous sediments (Upper Endybal'sk formation and its analogues -- P_2^2. The Upper Endybal'sk time was marked by continued regression and rapid shallowing of the

basin. Regional uplifts and intensified erosion caused increased contribution of detrital material from the west and also, for the first time, from the region of the Adychansk anticlinorium to the east. Broad belts of often coarse-grained sediments of bars and similar depositional forms of the seashore, merging locally into alluvium (West Gradyga and Uyana Rivers), developed both in the west and in the east. The coarsest deposits were formed along the slopes of the Aldan shield and to a lesser extent along the Anabar massif, the main contributors of the detritus. Sand and less frequently alternating sand, silt and clay were deposited in the more remote parts of the basin.

The central cordillera, outlined in the previous stage of development of the basin, became more prominent. A zone of decreased

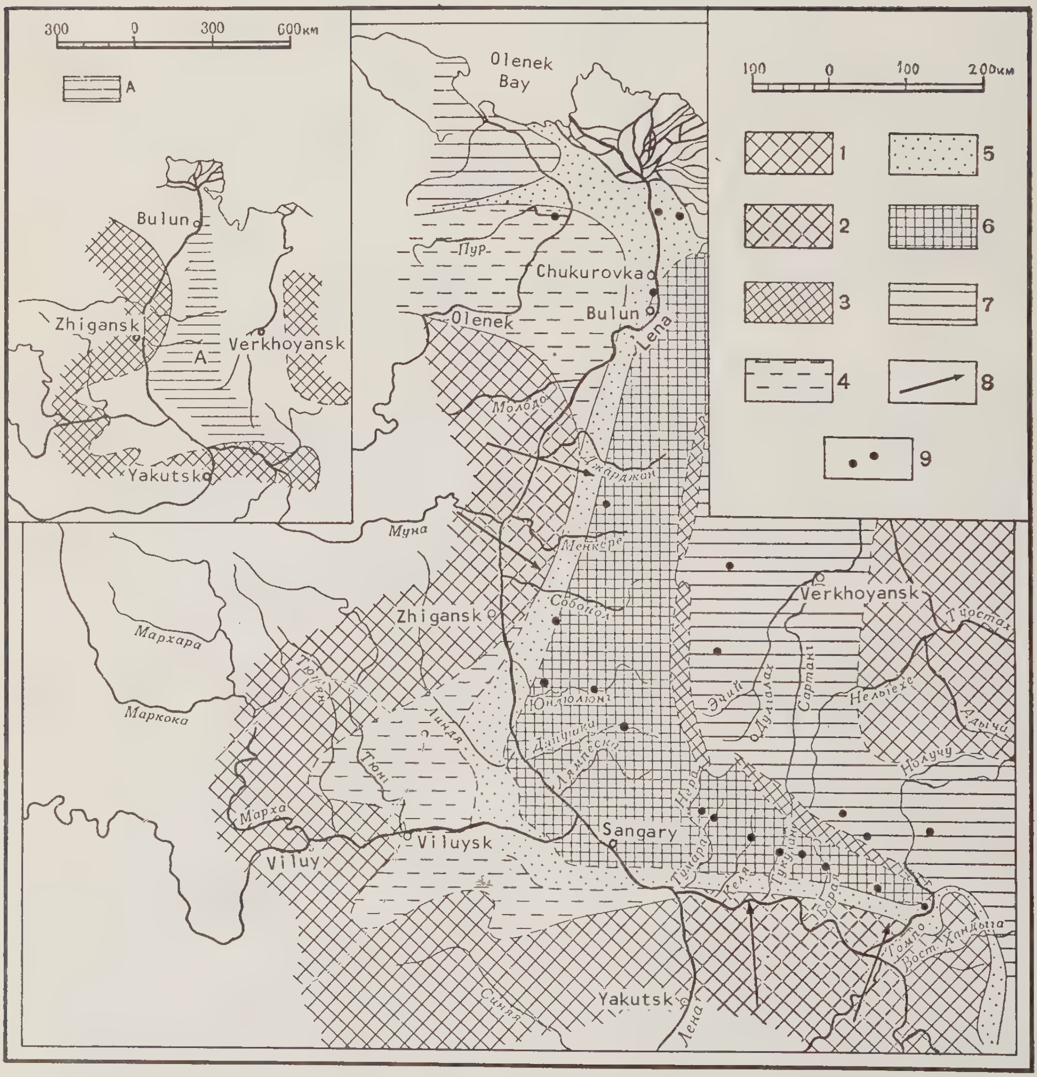

Fig. 4. Facies distribution during the first half of the Late Permian epoch.

1 - Weakly-dissected, low land areas; 2 - dissected, uplifted land areas; 3 - areas of very limited sedimentation or erosion; 4 - sand-silt-clay deposits of lagoons, gulfs and coastal lakes; 5 - littoral marine deposits, mainly sand; 6 - flysch-like deposits of sand, silt and clay in the relatively deep parts of the basin; 7 - clay and silt of the open sea; 8 - main directions of sediment transport; 9 - observation points.

Terrigenous mineralogic provinces: A - leucoxene-zircon-tourmaline with rutile and apatite.

thickness of sediments coincides with the present divide of the Verkhoyansk Range. It is possible that towards the end of Late Endybal'sk time, the cordillera stood partly above sea level as a chain of low islands trending in the direction of the axis of the Verkhoyansk meganticlinorium. In the central area (Nera-Bigidzhan interfluve) immediately adjacent to the Viluy depression, a specific environment was created which led to periodic formation of coal-bearing beds. The western part of the central section of the Verkhoyansk Range, together with the Viluy gulf, was periodically separated from the marine basin by bars and extensions of sandy stream channel deposits and spits along the uplifted

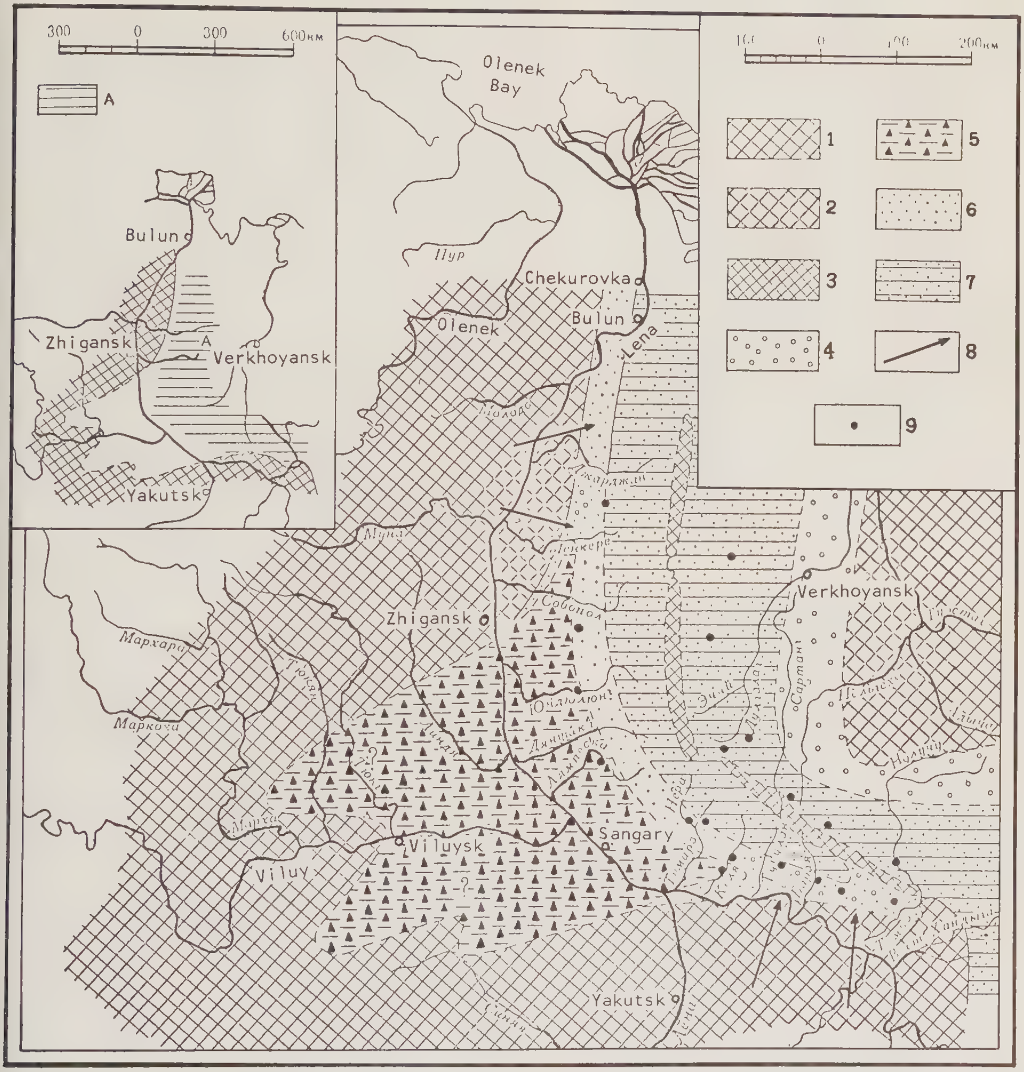

Fig. 5. Facies distribution at the end of the Late Permian epoch.

1 - Weakly-dissected land areas; 2 - dissected, uplifted land areas; 3 - areas of greatly diminished sedimentation and erosion; 4 - marine littoral and deltaic sand and conglomerate; 5 - carbonaceous deposits, sand, silt and clay, of gulfs, lagoons and coastal lakes; 6 - nearshore sandy sediments (spits, bars, etc.); 7 - marine sand and silt of the shallows; 8 - main directions of sediment transport; 9 - observation points.

Terrigenous mineralogic provinces: A - zircon-tourmaline-apatite with garnet.

areas of the Aldan and Anabar massifs. West of the belt of bars, beds of the lagoonal facies were deposited (Fig. 5).

The slight contribution of detritus from the low shores of the Viluy gulf and its isolation from the sources of sediment produced a fine-grained lagoonal facies accessible to study only in the extreme eastern part of the area (Nara, Dyanushka, Yundyulyung Rivers and in the Kitchan region). The environment of the receding sea was favorable for the development of bays, lagoons, and shallow basins and coastal lakes, which were periodically covered with vegetation and locally changed into peat bogs.

The stage of formation of the Upper Permian coal-bearing sediments was contemporaneous with further differentiation of vertical movements in the Verkhoyansk Range region. Despite continued uplift of the core of the meganticlinorium, both limbs subsided considerably in the east and in the southwest. The thickness of the coal-bearing sediments reached 2500 m on the eastern slope and 1800 m on the western. On the western slope, the zone of maximum subsidence was located in the central section but extended somewhat into the region of the Viluy depression proper (Fig. 5). The Upper Permian coal-bearing basin lay at right angles to the folded arc of the Verkhoyansk region.

The sediments of the coal-bearing complex of the western slope belong to a single, terrigenous mineralogic province represented by the association of zircon, garnet, tourmaline, rutile and other minerals. The appearance of garnet connected with the erosion of the strongly metamorphosed Precambrian rocks of the Aldan shield and the Anabar massif is very characteristic. During the Upper Endybal'sk time, the garnet schist of the source area was exposed for the first time, and was subjected to intense erosion during the succeeding Mesozoic period.

THE LOWER TRIASSIC EPOCH

The time of accumulation of the redbeds complex. The general regressive movements which affected the entire northeastern region of the Soviet Union at the end of the Permian and the beginning of the Triassic and which led to the emergence of a considerable part of it (the Okhotsk-Kolyma watershed, the Chukotsk peninsula, etc.) were complicated in the folded Verkhoyansk region by a slight transgression. Rather intense subsidences persisted here, and a normal marine basin continued to exist in the region of the eastern slope and the adjacent Yana syncline.

In the region of the western slope, the Lower Triassic basin has a number of sedimentary facies, each representing a specific characteristic of the regime of sedimentation (Fig. 6).

In the central section of the Verkhoyansk Range, the transverse basin extending into the Viluy depression persisted into the new epoch in its entirety. It became filled with red sand and silt which, as their textural and other features indicate, were typical deltaic sediments and are probably replaced by alluvium in the direction of the Viluy depression. The new mineral association is very characteristic of the redbeds. It contains minerals absent from the Permian sediments, such as epidote, zoisite, hematite, kyanite, allanite and garnets. The presence of this specific association is due to the evolution of a new source of terrigenous materials. In Early Triassic time the transverse downwarp of the Viluy depression became the site of a large stream which emptied into the Verkhoyansk basin and transported large amounts of detritus from the region of the Baikal-Potomsk uplands. The mineral association, which is first present in the Lower Triassic rocks of the Verkhoyansk Range and persists in the younger Mesozoic rocks in the Jurassic and Cretaceous strata of the southwestern and western parts of the Viluy depression, was derived from the erosion of the ancient schist of the Baikal-Potomsk uplands [15].

A lagoon regime existed in the broad area separated from the open marine basin by the central cordillera. Here were accumulated gray sand and clay lacking a normal marine fauna but containing rather abundant Estheria, indicating an abnormal salinity of the basin.

The mineralogic composition of the sediments in the latitudinal section differs from that in the central section. As before, the sediments for this region were furnished by the uplifted areas of the Aldan shield. The mineral association containing biotite, with garnet, chlorite and chloritoid, indicates continued, intensified erosion uncovering the schist of the deeper metamorphic zones probably belonging to the biotite-garnet facies. In the region of juncture of the latitudinal and central sections, there is a zone of mixed detrital material. In the second half of the Early Triassic epoch the area of deposition of terrigenous material brought to the delta became larger, and the area of distribution of the "epidote association" was extended to the latitudinal section. It is possible that at the end of the Early Triassic the "epidote association" was extended over the entire latitudinal section, but it is difficult to be certain of this because the upper beds of the redbeds complex have been

removed by erosion. An indirect confirmation of hypothesis is the universal presence of epidote in the basal beds of the Baylyk series formed from erosion and redeposition of Lower Triassic rocks [12]. Marine sediments were deposited in the meridional section. A band of littoral sand and silt stretches along the slopes of the Anabar massif, borders the Olenek uplift and continues into the Khatanga depression. It is followed by fine-grained, mainly argillaceous sediments traceable far to the east into the region of the eastern slope and the Yana syncline. On the western slope of the northern Verkhoyansk Range (the Orlugan Range), they contain subordinate beds of limestone. The detrital material of the

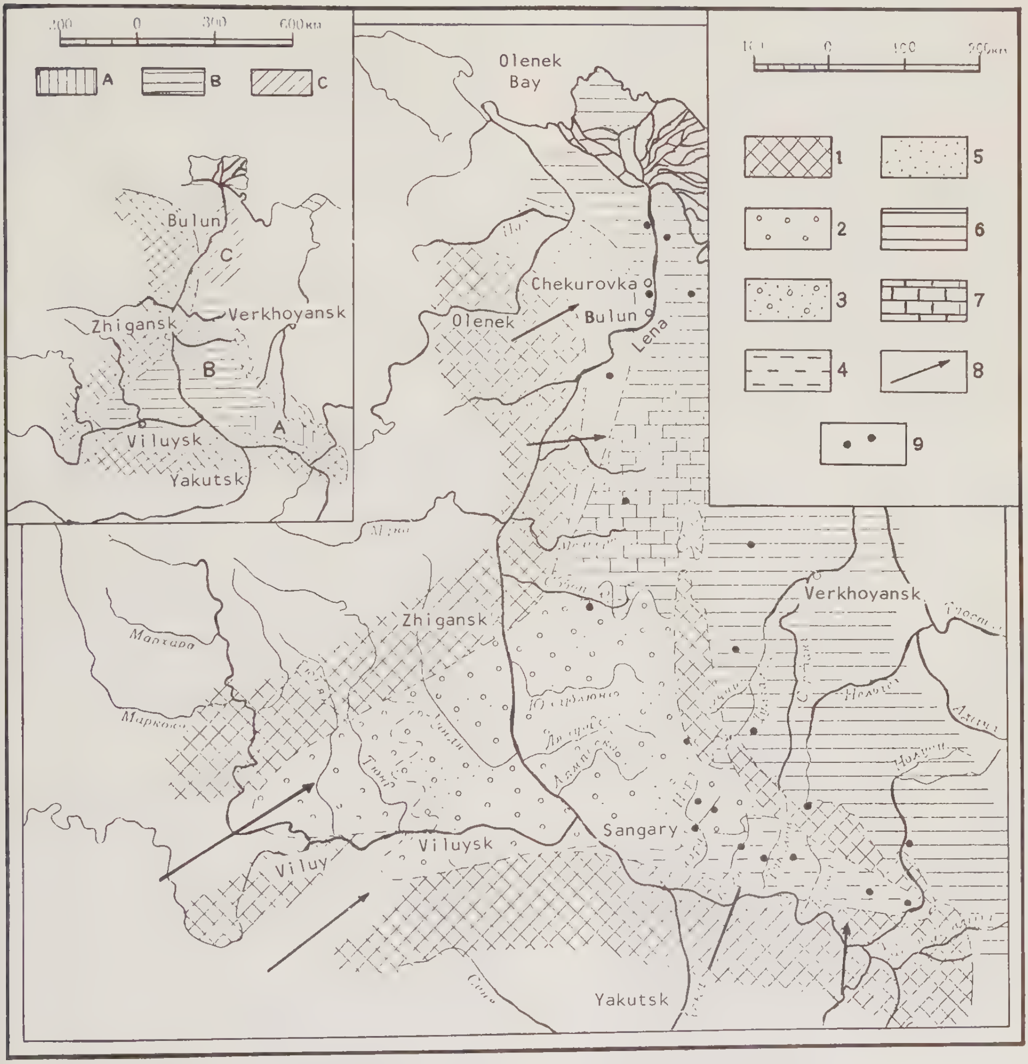

Fig. 6. Facies distribution at the end of the Early Triassic.

1 - land; 2 - alluvium, mainly sand; 3 - redbeds, sand and silt of a submarine delta; 4 - gray lagoon sand, silt and clay; 5 - littoral sand; 6 - marine clay; 7 - marine clay and carbonate sediments; 8 - main directions of sediment transport; 9 - observation points.

Terrigenous mineralogic provinces: A - biotite-garnet with chloritoid and apatite; B - epidote-zoisite-garnet with hematite, allanite and kyanite; C - biotite-chlorite with zircon and garnet.

northern Verkhoyansk Range came from the Anabar massif and in part from the material delivered by the southeastern stream and distributed by the currents.

During the Early Triassic, the central cordillera was an archipelago of low islands separating the basin of the eastern slope from the lagoon and delta facies in the west. The islands were periodically submerged and the sea penetrated into the western slope region crowding the deltaic facies far to the west. A local transgression occurred in the central section during Middle Kel'tersk time, when the deltaic sediments were replaced by relatively deep-water clay with a typically marine ammonite fauna.

The different source areas of detrital material are responsible for the presence within the western slope of the Verkhoyansk Range of three terrigenous mineralogic provinces: 1) the southeastern biotite-garnet and chlorite province, 2) the central and most extensive epidote-zoisite province with allanite and kyanite, and 3) the northern biotite-chlorite-garnet province.

The close similarity between the mineralogic composition of the southeastern and northern provinces resulted from the uniformity in composition of the basement rocks uncovered by regional erosion.

The most intensive subsidences during the period of accumulation of the Lower Triassic sediments occurred at the juncture between the central and meridional sections (the Dyanushka and Natara Rivers) in predominantly deltaic deposits. Less intense subsidences occurred in the latitudinal section in the northern regions. The entire east slope was also a region of intense subsidence (Fig. 6).

In concluding the description of the sedimentation conditions during the Early Triassic it is noteworthy that this epoch coincided with a climatic change. The moderately moist climate of the Upper Permian changed to a hot and dry climate, as indicated by the presence of limestone, which is almost completely absent from the Permian deposits and by the appearance of the characteristic red coloration on the deltaic deposits of the central section.

The change towards aridity at the end of the Paleozoic was regional and has been recorded, according to G. F. Krasheninnikov [10], in many extensive areas of Asia, Europe, and North America.

THE MIDDLE TRIASSIC EPOCH

During the Middle Triassic epoch sizable uplifts occurred almost everywhere in the Verkhoyansk region and in the adjacent parts of the platform. The sea receded to the north and east. Within the boundaries of the Verkhoyansk Range, marine littoral sandy deposits with a Middle Triassic fauna are known only in the north in the region of the Kharaulakh Mountains and in the northern Orulgan Range. Recently, Middle Triassic rocks have been found by L. P. Smirnov and B. S. Abramov on the eastern slope and in the upper reaches of the Tompo River. It is probable that an uninterrupted belt of littoral deposits of the Middle Triassic sea extended along the east slope of the uplifted structure of the Verkhoyansk Range. In all other regions of the Verkhoyansk Range, the eroded Early Triassic surface is overlain by a thick conglomerate-sandstone complex of Late Triassic-Early Liassic age.

Some idea of the configuration of the Middle Triassic uplift may be gained from the attitude of the basal beds of the Baylyk series on the western slope and the Karnic sediments of the eastern slope.

The available data indicate that the Middle Triassic uplift was of the fault-block type and consisted of a series of lowered and relatively uplifted zones extending throughout the Verkhoyansk region. The axis of the first uplifted zone coincided with the central cordillera and trended approximately along the present divide. It is possible that in the northern regions of the central section it deviated slightly to the east, as indicated by the considerable diminution and sometimes complete disappearance of the Lower Triassic deposits in the region of the middle course of the Batyntay River.

The axis of the second uplift passed along the middle of the present western slope of the Verkhoyansk Range. It is believed by V. S. Vyshemirskiy that on the western slope in the region of the right bank of the lower course of the Nera River, the Lower Triassic deposits are thinnest because of the erosion of the entire upper Kel'tersk part of the middle Kel'tersk subformations. Toward the main divide and the foothills of the range, the thickness of the Middle Triassic deposits increases because of the appearance of the upper beds of the Kel'tersk formation.

To the southeast, along the trend of the western slope, the zone of intense erosion of the Middle Triassic deposits can be traced over a large territory of the latitudinal section to the Barai River. The thickness of the deposit, which in this belt consists of lagoon facies, does not exceed 500 m (sections on the Tynkychan, Ybykan, Vostochnaya Gradyga and Barai Rivers). In the region of the Zapadnaya Gradyga River,

there are angular unconformities between the Lower Triassic rocks and the sediments of the Baylyk series.

In the region of maximum erosion of the Lower Triassic strata in the southern part of the central section and in the latitudinal section, there are basaltic flows probably related to the large faults of the folded basement in the zone of Middle Triassic uplifts.

Thus, during the time subsequent to the deposition of the Lower Triassic sediments and Late Triassic (Karnic) transgression, a considerable part of the Verkhoyansk region was subjected to a large uplift followed by partial erosion of the Lower Triassic sediments.

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HISTORY OF MESOZOIC SEDIMENTATION IN THE WESTERN VERKHOYANSK RANGE AND THE VILYUY DEPRESSION

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1. LITHOLOGIC AND STRATIGRAPHIC CHARACTERISTICS OF THE SECTIONS

Within the Mesozoic framework of the Verkhoyansk Range, including the transverse structure of the Viluy depression [18], three types of sections representing different structural zones of the region may be distinguished. They are: 1) the sections of the platform slopes along the marginal downwarp and the transverse Viluy depression, 2) the sections of the outer or marginal part of the Verkhoyansk geosyncline and 3) the sections of the central and most deeply buried areas of the Viluy depression which are intermediate between types one and two (Viluy and Namsk boreholes).

There are substantial differences in structure between the platform and geosynclinal sections, but both contain clearly defined complexes or formations which follow each other in a definite order and reflect the pattern of changes of the physical and geographical environments during various stages of the Mesozoic cycle. The cycle began in the Late Triassic after the regional Middle Triassic uplifts which terminated the Late Paleozoic cycle and ended in the Late Cretaceous [7].

On the western slope of the Verkhoyansk Range the following time-rock complexes or formations can be distinguished in the Mesozoic cycle: 1) the lower sand and conglomerate complex (T_3 - J_1^1) representing a transgressive stage, 2) the sand, silt and clay complex (J_1^{2+3}) representing the maximum extension and the stillstand of the basin, 3) the upper sand (J_2) of the initial stages of regression, and 4) the coal-bearing complex (J_3 - Cr_1) which represents the regressive stage of the cycle.

The homologues of the formations of the outer geosynclinal zone are easily identified in the platform region of the Viluy depression although they possess a number of individual characteristics. In the region of the greatest subsidence within the depression there are also sediments of the youngest sandy alluvial formation (Cr^{alb} -- Cr_2), which reflects the final stage of folding of the Verkhoyansk geosyncline. The presence of analogous groups of formations in the different structural regions makes the correlation of their sections easier. These formations form the basis for the stratigraphic column of Table 1.

The Mesozoic sediments of the Viluy depression were subdivided into three genetically different groups as early as A.G. Rzhonsnitskiy's time according to a perfectly correct principle: the lower, sandy freshwater series; the middle sequence of marine sand and clay; and the upper coal-bearing series. Further investigations [2, 4, 5, 8] introduced a considerable refinement of this subdivision but did not change its basic principle.

It was somewhat different in the Verkhoyansk Range. N.P. Kheraskov's column [17], widely used until recently, contained only two genetically uniform rock complexes: the sandy Baylyk formation (J_1 -- J_2) and the coal-bearing Chechuma and Sangarsk formations (J_3 -- $Cr^{(?)}$). The marine complex of sand, silt and clay was not included in the column, and this made it difficult to correlate the Verkhoyansk Range section with that of the platform as well as with the individual sections of the western slope of the range. The marine sand, silt and clay complex of the Verkhoyansk Range, contemporaneous with the marine sediments of the Viluy depression, was first defined in 1951-1952, independently, by the Dal'stroy geologist V.N. Andrianov on the Ybykan River and by the present author on the Zapadnaya Gradyga and Kelya Rivers. The recognition of this complex made it possible to correlate the sections of the western Verkhoyansk Range with those of the Viluy depression (Fig. 1) and to establish the contemporaneity of sedimentation in these two structures. Recently the marine complex (J_1^{2+3} -- J_2^1) has been traced in the central and meridional sections on the Lyampeske and Dyanushka Rivers by V.M. Mel'nikov, on the Yundyulyung River by G.S. Borushko and A.I. Ushakov, and on

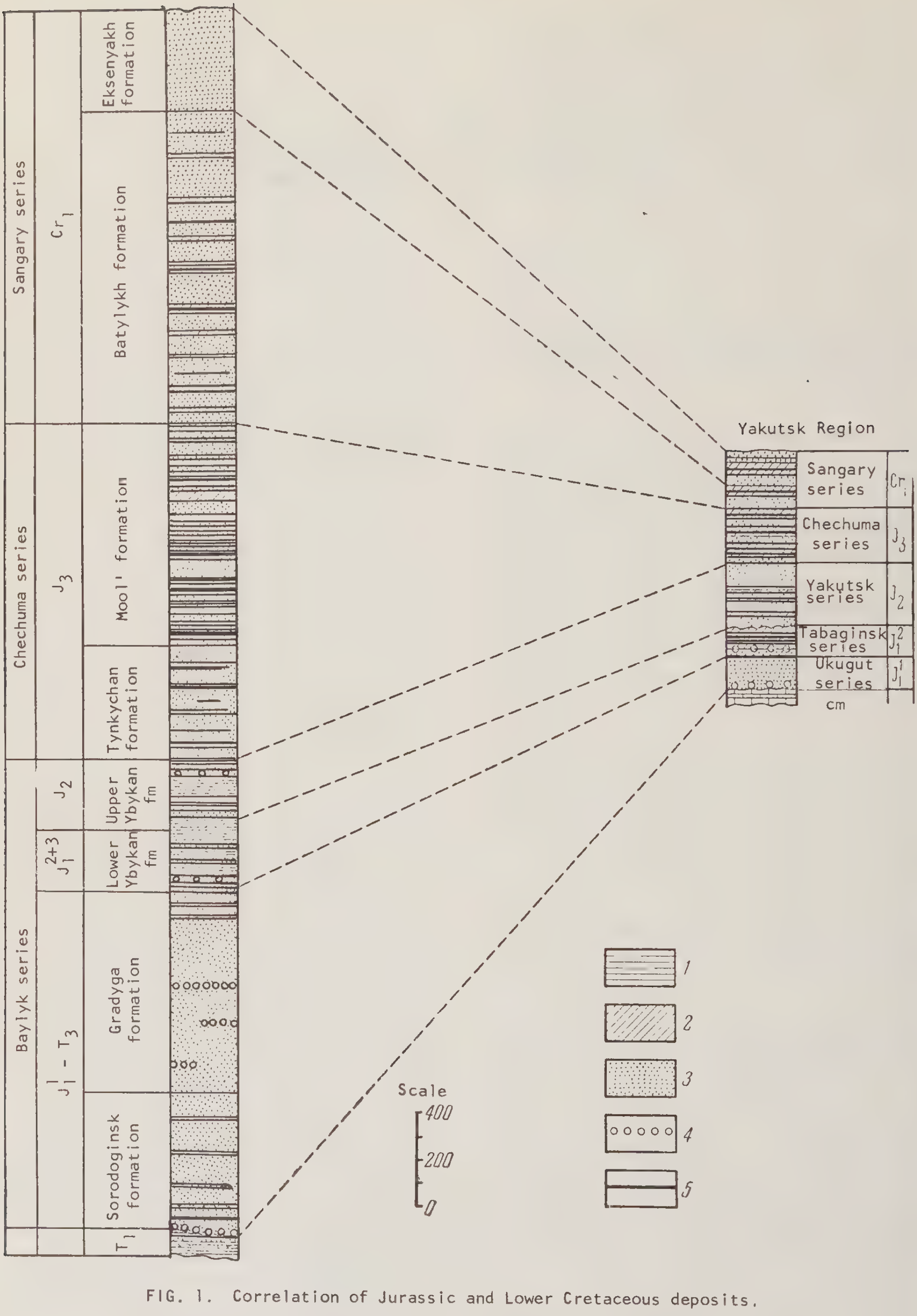

FIG. 1. Correlation of Jurassic and Lower Cretaceous deposits.

1 - clay, 2 - siltstone, 3 - sandstone and sand, 4 - conglomerate, 5 - coal.

the Begidzhan River by V.V. Panov [13].

As a result of these investigations Kheraskov's Baylyk formation has been raised to the rank of a series and subdivided into three genetically uniform rock complexes: 1) the sand-conglomerate complex (T_3 -- J_1^1), 2) the sand-silt-clay complex (J_1^{2+3}) and 3) the upper sand complex (J_2).

On the western slope of the Verkhoyansk Range, the sand-conglomerate (T_3 -- J_1^1) complex is subdivided into two formations, the Sorodoginsk and the Gradyga. The scope of the present paper does not permit a detailed description of these beds. Their most important features for the purposes of correlation are given in the table (Table 1).

The Sorodoginsk formation lies unconformably on the eroded Early Triassic surface and contains a basal conglomerate in its lower part. In the eastern part of the region, between the Uyan and Zapadnaya Gradyga Rivers, the conglomerate is up to 12 m thick and it contains pebbles of igneous and metamorphic rocks foreign to the western Verkhoyansk region. The conglomerate decreases in thickness to the west, and pebbles and blocks of the underlying Lower Triassic rocks are its main constituents. The lithologic composition of the formation is very uniform, consisting of light-colored massive sandstone with subordinate beds of platy siltstone and silty shale.

The Gradyga formation has a gradational contact with the Sorodoginsk formation and is distinguished from it by coarser-grained sandstone and the constant presence of conglomeratic layers and lenses.

The sand-conglomerate complex is thickest in the central section and diminishes to the north and southeast. In the extreme southeastern regions (Uyana and Tompo Rivers) the Sorodoginsk formation apparently wedges out and the thickness of the Gradyga formation diminishes to 300 m.

The Sorodoginsk and Gradyga formations are composed essentially of nearshore marine sediments. These are typical deposits of spits, bars and other depositional forms of the seashore. They are well sorted because of repeated redeposition. The environment was not favorable for the existence of a fauna (probably because of the considerable freshening of water in the nearshore zone) and the sediments are unfossiliferous; thus it is difficult to determine their exact age. However, because the sand and conglomerate beds lie on fossiliferous Lower Triassic strata and are overlain by Middle Liassic beds, we refer them to the Upper Triassic or Lower Liassic. During the Middle Triassic, an interruption in sedimentation occurred almost everywhere in the area of the western slope of the Verkhoyansk Range.

On the basis of lithologic and paleogeographic analyses, the Sorodoginsk formation may be the equivalent of the Derbekinsk formation (T_3^{kar}) defined by A.V. Zimkin, L.N. Smirnov and B.S. Abramov on the eastern slope of the range (headwaters of the Tompo River), and the Gradyga formation is equivalent to the Nel'gekhinsk ($T_3^{nor-ret(?)}$) and Delin'yaksk (J_1^1) formations.

The sand and conglomerate deposits of the platform constitute the Lower Liassic Ukugutsk formation. Its thickness does not exceed 200 m in the southeast (Aldan River area) and decreases to 30 m on the northwestern limb (Tyung and Markha Rivers area). In the region of the Linda River and the town of Zhigansk, the Ukugutsk formation wedges out. Although it is composed of the same rock types as the formations of the geosynclinal belt, i.e., sand, sandstone and conglomerate, its facies and petrography are quite different. The Ukugutsk rocks are mainly alluvium, chennel and floodplain sediments deposited at the mouths and in the deltas of streams which flowed into the Verkhoyansk basin.

The Ukugutsk formation contains two well-defined detrital mineral provinces, the western (Viluy, Ygetta, Markha and Tyung Rivers) epidote-hornblende province and the southeastern (Sinyaya River, the Yakutsk region and the Amga and Aldan Rivers) garnet-zircon province. It is important to note that these provinces persisted through the entire Jurassic period.

The Ukugutsk formation is overlain by a sand, silt and clay complex (J_1^{2+3}) which is referred to the Middle and Upper Lias.

These sediments on the western slope have been defined by the author as the Lower Ybykan formation. The sediments vary somewhat in character in different areas of the western slope of the range. Within the latitudinal section (Kelya, Ybykan, Zapadnaya Gradyga, Boraya and Uyana Rivers), the formation consists of finely-graded, flysch-like, fine-grained silty sandstone, siltstone and silty shale alternating with subordinate groups of lighter-colored, fine-grained, and less frequently medium-grained sandstone (average thickness between 5 and 20 m). The thickness of the formation is about 300-350 m. In the central section (Kitchany village, Dyanushka and Lyampeska Rivers area) the formation becomes very sandy. The character of the rocks, their relatively coarse grain, the presence of shallow water ripple marks, scour-and-fill, etc., indicate

that the basin was very shallow in this section. To the north, in the regions of the Begidzhan, Sobopol and Menkgera Rivers, according to the data of V.V. Panov [13], A.E. Kiselev and others, the formation has the same lithologic and facies character as in the latitudinal section. The age of the formation as indicated by the rather abundant fossils in Middle to Upper Lias (see Table 1).

Over a large area of the Viluy depression the sand, silt and clay complex has a definite bipartite structure [4]. It consists of a lower sandy unit with Harpax laevigatus and an upper one containing Leda and belemnites. The sharpness of this division disappears only in the southeastern part of the depression (in the Yakutsk-Aldan River region), where almost the entire section consists of sandstone, and also in the extreme southwestern regions (Bautobiya and Chona Rivers area), which lie beyond the depression.

A new stage in the development of the Viluy depression and the Verkhoyansk Range began in the Middle Jurassic with gradually increasing regression, the initiation of uplifts in the surrounding areas, the gradual shrinking of the marine basin. The upper sandy complex (J_2) was deposited during the beginning of this stage. The complex contains many facies. In the western Verkhoyansk Range it is represented by marine sand and interbedded sand and silt of the Upper Ybykan formation, which has a gradational contact with the underlying beds. The Middle Jurassic marine sandstone of the outer slopes of the Aldan and Anabar massifs are similar but have a shallow-water aspect. Farther west, along the edge of the depression, beginning approximately at Yakutsk on the southern side and at the Markha River on the northwestern side, the marine seiments are replaced by littoral and littoral-continental deposits of the Yakutsk formation, composed of sandstone with subordinate layers of siltstone and clay. The continental facies increase in importance toward the west, where thin coal beds appear in the upper parts of the formation (Viluy and Ygetta Rivers). The erosional contact of the Yakutsk formation which the underlying beds is most pronounced in the western part of the depression. The base of the formation everywhere contains a group of coars, alluvial sandstone beds (10-20 m thick) enriched in kyanite.

The overlying coal-bearing complex (J_3 -- Cr_1) in the Verkhoyansk region and the Viluy depression includes sediments of the Upper Jurassic (Chechuma series) and Lower Cretaceous and Aptian ages (Sangary series).[1]

Three types of structures may be distinguished in the complex: 1) the platform type developed along the edges of the depression, 2) the type transitional between the platform and the downwarp developed in the central, most strongly downwarped areas of the depression and at the junction of the latter with the downwarp (Viluy and Namtsinsk boreholes) and 3) the downwarp type of the Verkhoyansk region (Table 1).

The Chechuma series (thickness 1000-1500 m) has been divided by the author, in the latitudinal section of the Verkhoyansk region (Kelya, Tynkychan and Ybykan rivers), into the Tynkychan and Mool' formations. The characteristics of the formations are given in Table 1. In the Tynkychan formation, sandstone is dominant. The position of the Mool' formation in the section and the predominance of sediments deposited relatively far from shore (siltstone with characteristic textures, high carbonate content in all rocks, graded beds, etc.) permit correlation of the Tynkychan formation with the coal-bearing Dzhaskoy formation of the eastern slopes of the Aldan and Anabar massifs (vicinity of Zhigansk) and the Mool' formation with the marine Sytoginsk formation (Table 1).

It has not been possible, so far, to subdivide the Chechuma series into formations in the sections of transitional type (Viluy and Namtsinsk boreholes). However, the general type of structure, with dominant sandstones in the lower part and silt and clay in the upper, accompanied by an increase in the "more marine" facies in the upper half of the sequence, is preserved here also. The thickness of the series is about 700 m.

Along the edges of the depression the most complete structure of the sections of the Upper Jurassic coal-bearing beds is present in the vicinity of Yakutsk, where these beds have been penetrated by a number of boreholes near the village of Kil'dyamtsy. The thickness of these sediments does not exceed 300 m and they encompass three large cycles, each of which begins with a thick group of sandbeds passing into interbedded sandstone, siltstone and clay with

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[1] On V.A. Vakhrameyev's suggestion [4], the Chechuma and Sangary coal-bearing formations of the Verkhoyansk region defined by Kheraskov have been extended to the Viluy depression and raised to the rank of series. The Upper Jurassic age of the Chechuma series and the Lower Cretaceous age of the Sangary series were established by Vakhrameyev on the basis of plant fossils.

coal. Sediments with this type of structure in the Chechuma series were defined by the author as the Kil'dyamtsy formation.

The contact between the Upper Jurassic and Lower Cretaceous deposits is gradational, and it is often difficult to draw a boundary between them, especially as leaf impressions are rather scarce and the change in pollen and spore profiles is gradual (V.A. Vakhrameyev, N.A. Bolkhovitina). In the central and latitudinal sections of the area adjacent to the Verkhoyansk Range (Chechuma and Zapadnaya Gradyga Rivers) and the nearby parts of the platform (Ust'-Viluy, Yakutsk and other regions), the separation of the Upper Jurassic and Lower Cretaceous beds can be successfully made on the basis of accessory mineral associations. The Chechuma series is characterized by the garnet-zircon-biotite-apatite association, which is replaced abruptly by an epidote-zoisite association accompanied by allanite and a characteristic red-brown garnet in the Sangara series. To the west the "mineralogic boundary" loses its stratigraphic significance. In the Viluy borehole, according to A.E. Kiselev, epidote is present in the upper half of the Chechuma series. Still farther west, epidote is the most typical mineral in all Jurassic formations.

The Sangary series is divided into the Batylykh formation, approximately corresponding to the Neocomian stage, and the Eksenyakh formation, equivalent to the Aptian stage (the criteria for correlation are given in Table 1). These formations are especially clearly defined in the area adjacent to the Verkhoyansk Range and in the central part of the Viluy depression. The thickness of the Sangary series in the Verkhoyansk region is as much as 2500 m, but it diminishes to 1000 m in the central part of the depression.

The two detrital mineral provinces which existed in the Viluy depression throughout the Jurassic disappear in the Early Cretaceous and are replaced by one epidote-hornblende province which covers not only the Viluy depression but all of the Verkhoyansk region.

The Mesozoic cycle was terminated by the deposition of a sandy alluvium complex which included the upper part of the Lower Cretaceous Kharyryk formation (Albian)[1] and the Upper Cretaceous. This complex developed only in the most strongly downwarped areas of the Viluy depression and is represented by the thick Viluy series (800 to 1000 m thick) composed of white, cross-bedded kaolinized sandstone with occasional layers and lenses of "pudding stone" conglomerate and subordinate beds of silty clay, brown coal and lignite. The general character and petrographic composition of this complex distinguishes it sharply from the underlying beds (Table 1).

II. HISTORY OF SEDIMENTATION IN THE WESTERN VERKHOYANSK REGION AND THE VILUY DEPRESSION DURING THE MESOZOIC CYCLE (T_3 -- Cr_2)

Sedimentation of the Mesozoic cycle began in the Late Triassic. After the regional Middle Triassic uplifts which terminated the Late Paleozoic cycle, the sea receded to the east and north. A new transgression was marked in the western Verkhoyansk region by the deposition of a sand and conglomerate complex (T_3 -- J_1^1) on the eroded surface of the Lower Triassic sediments. The transgression was complicated by a series of smaller transgressive and regressive waves and the entire movement may be divided into three general stages.

The first stage, during Karnian time, was the period of accumulation of the Sorodoginsk formation. The sea, advancing from the east, spread over the entire Verkhoyansk region and possibly invaded the central parts of the Viluy depression. The belt of marine nearshore deposits, sand and local sand and conglomerate of the Sorodoginsk formation extended along the western side of the latitudinal section (Tynkychan and Zapadnaya Gradyga Rivers), crossed the present Verkhoyansk Range somewhere near the upper courses of the Boraya and Uyan Rivers and extended into the region of the eastern limb of the Setta-Dabansk anticlinorium, a land mass at that time. From the latitudinal section in the north to the northern Kharaulakh Mountains, the littoral sediments are more and more fine-grained and pebbles are not present even in the basal beds.

[1] Originally the Khatyryk formation was defined by the author and N.A. Bolokhovitina on the basis of the Namtsinsk borehole section and was named the Namtsinsk formation. However, the name "Namtsinsk formation" was assigned to Tertiary deposits on the government geologic map of the U.S.S.R., sheet P-52 (Gosgeolizdat, 1957), it was advisable to propose another name for the formation and call it Khatyryk after the village where the Namtsinsk borehole is located.

The second stage, corresponding to the Norian and Rhaetian times, was characterized by sizable uplifts in the region of the western and southwestern land masses, by increased accumulation of detrital material and by diminution and shallowing of the basin in the territory under discussion. The sea retreated from the north, and the region of the Anabar massif and the Kharaulakh Mountains emerged as dry land not invaded by the sea again until the Middle Lias.

The third stage, occurring during the Early Lias, was marked by a sharp increase in the areas of deposition. Downwarping occurred over the entire area of the Viluy depression including its southern and western edges, and sand and sandy-conglomeratic sediments were deposited in the lower courses of the stream flowing into the basin.

The advance of the sea to the west, into the Viluy depression, caused a general displacement of all facies. Along the present western slope of the Viluy depression (upper course of the Tompo River), thin agrillaceous sediments accumulated in relatively deep water. They contain a typical marine fauna with Schlotheimia ex gr. angulata Schloth (B. S. Abramov). This facies apparently extended nearly north-south, parallel to the present trend of the Verkhoyansk Range. Along the western slope of the range, shallow-water, sandy deposits were formed extending in tongues into the region of the Viluy gulf. Coarser deposits were limited to the peripheral belt of the Anabar and Aldan land masses. Here, deposits of bars, spits, submarine bars and submarine stream channels are well developed, but are replaced to the south and southwest by subaerial alluvial-deltaic sediments (Fig. 2).

The larger streams flowing from the eastern slope of the Aldan massif and from the Baikal-Patomsk uplands entered the basin in the southeast and southwest. The thick conglomerate of the southwestern part of the depression was laid down during the first half of the Lower Liassic epoch and is typical of channel deposits of swiftly flowing streams which deposited their load on the margin of the piedmont plain on the southwestern edge of the depression. In the north, towards the central areas of the depression (Kempendyay region) the amount of pebbles deposited diminished rapidly. The northeastern side of the depression (the region of the Markha and Tyung rivers) received a deposit of distinctive fine-grained sand and clay. Evidently this area was a partly closed fresh-water lagoon which received material from the Baikal-Patomsk uplands in the south and from the Anabar massif in the north.

Among the sediments of the sand and conglomerate complex of the Viluy depression and the western Verkhoyansk Range, there are three clearly-defined, terrigenous-mineralogic provinces: the northwestern (Viluy-Tyung) epidote-ilmenite-hornblende province, the southern (Sin'sk-Aldan) zircon-association with titanium minerals and a low content of garnet (Fig. 2).

The presence of different terrigenous mineralogic provinces in the Viluy depression and the western Verkhoyansk region was due to different provenances and to the irregular structure of the surface of the depression, which determined the distribution of detrital material in it.

The crystalline rocks of the Baikal-Patomsk upland and, in part, the western and northwestern trap areas served as the source of material for the western detrital minerals province [1, 3, 12].

The sharp localization of the epidote-hornblende association in the western and northwestern parts of the depression throughout all of Jurassic time, the considerably thinner Jurassic sediments in this region and, finally, the absence of any noticeable zone of displacement between the western and eastern provinces suggests the existence of a belt of northeast-trending uplifts along the northwestern edge of the depression. This belt of uplifts was apparently nothing but the relict of the Middle Triassic land which shut off the supply of the "epidote" material from the Verkhoyansk basin after Early Triassic time (V. D. Shutov) and limited it to the northwestern part of the depression.

The presence of the belt of uplifts is confirmed by geophysical data, which indicate a series of large positive gravity and magnetic anomalies in the region of Suntar and farther northwest [11].

In the eastern part of the depression and in the Verkhoyansk region, the main contribution of detrital material came from erosion of the ancient metamorphic and intrusive rocks of the central and eastern slopes of the central and eastern slopes of the Aldan shield. The southern areas of the Aldan shield (the middle course of the Aldan River between Mil' and Uchur rivers, the Tokinsk basin) are characterized by the presence of a tourmaline-zircon-leucoxene association, typical of the sediments of the western Verkhoyansk region as well. (In the strongly metamorphosed, Verkhoyansk rocks the leucoxene has been changed to anatase and brookite.) In the more northerly regions, along the entire southern limb of the depression (the sections on the Sinyaya River, in the Yakutsk region and on the Amga and

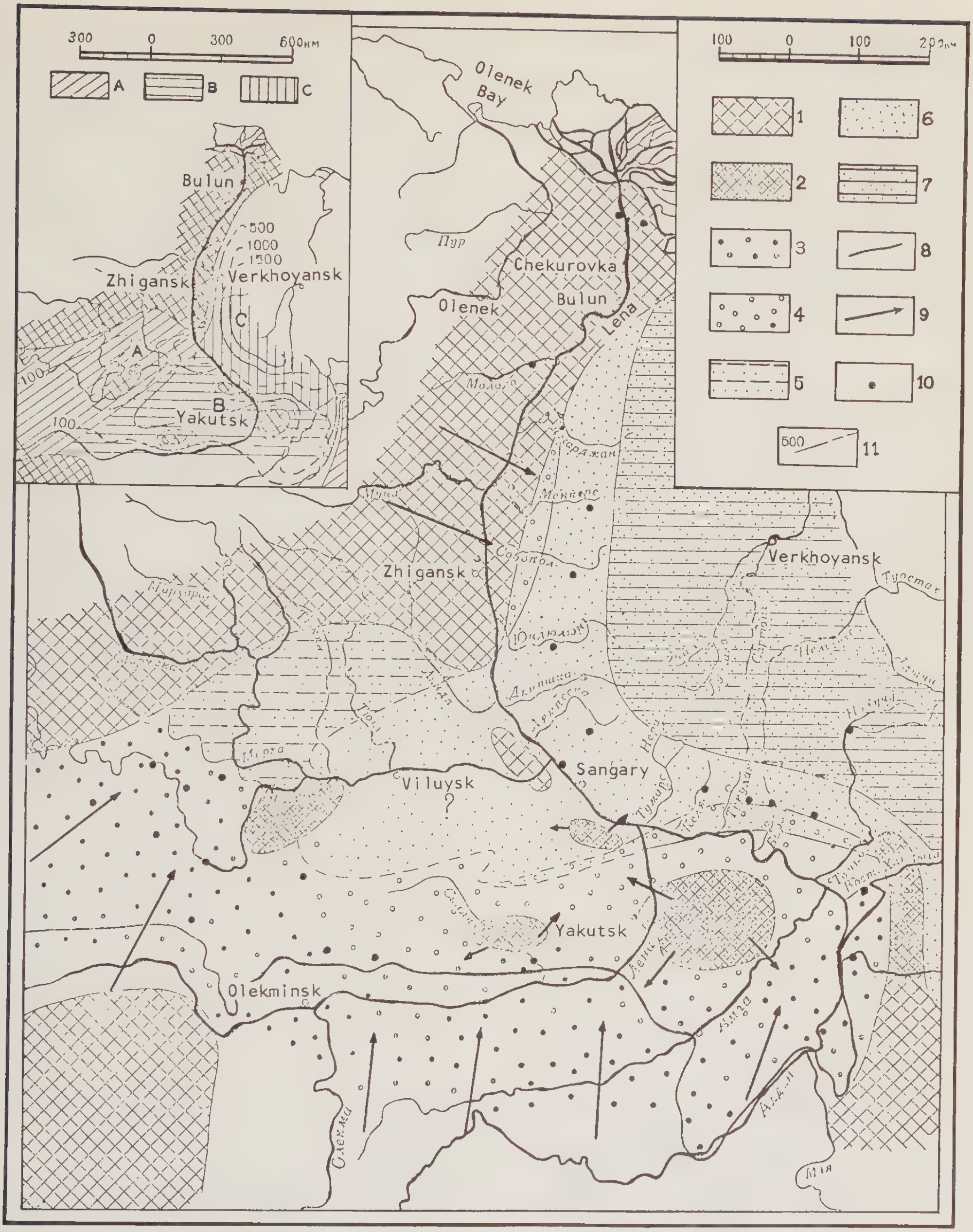

Fig. 2. Facies distribution in Lower Lias.

1 -- Land; 2 -- outcrop of the ancient basement in the region of sharply reduced sedimentation and erosion; 3 -- alluvial sand and conglomerate; 4 -- sandy sediments of stream mouths, deltas, submarine stream deposits, with an admixture of gravel; 5 -- sand, silt and clay of lakes, freshened lagoons and bays; 6 -- marine littoral and shallows deposits; 7 -- marine sand, silt and clay of the relatively remote areas of the basin; 8 -- boundary of the present distribution of Lower Liassic deposits; 9 -- direction of sediment transport; 10 -- observation points; 11 -- isopachs on the sand and conglomerate complex (J_1^1 -- T_3).

Terrigenous mineralogic provinces: A -- epidote-ilmenite-hornblende; B -- zircon-garnet association with kyanite and staurolite; C -- tourmaline-zircon association with titanium minerals.

Aldan rivers below Ust'Maya) the tourmaline-zircon association is strongly enrished in almandine, and at the same time kyanite and staurolite appear in it.

The abundance of garnet in the region of the southern edge of the depression is evidently due to the erosion of schist from the ledges of the Precambrian basement, which have been located by geophysical methods and drilling. It is noteworthy that the rocks of the ancient ledges revealed by drilling in the vicinity of Yakutsk also contain almandine schist.

The Verkhoyansk province, as already noted, received its detrital material from the southeastern part of the Aldan shield. An additional source was probably the zone of local uplifts and outcrops inherited from the Middle Triassic land and paralleling the general trend of the Verkhoyansk Range. Unlike the more southerly ledges of the crystalline basement, the Precambrian rocks here are covered by Permian and Triassic sediments. The presence of redeposited constituents of the Lower Triassic and Permian rocks in the Sorodoginsk and Gradyga formations can be clearly traced along the entire western slope of the Verkhoyansk Range from the Boraya River in the east to the Begidzhan River in the north.

The time of accumulation of the sand-silt-clay complex $(J_1^2 + {}^3)$ was marked by further broadening of the marine basin and by a short period of stability. The history of the basin during this time is divisible into two stages.

The first stage, covering the Middle Liassic, was characterized by the spreading of the sea far to the west into the Viluy depression and even beyond its boundaries into the peripheral zone of the Tungusska-Viluy downwarp. For the first time since Karnian time, the margin of the eastern slope of the Anabar massif was covered by the sea. This extensive transgression was preceded by a brief shallowing of the sea, as indicated by a rather wide distribution of thin conglomerate at the base of the complex (central and latitudinal sections of the Verkhoyansk Range, southern limb of the depression).

The main mass of material during the Liassic continued to come from southern sources. Along the southern and western slopes of the depression a broad band of nearshore sandy sediments was depsoited. They have a rather varied facies. In southeastern regions the proximity of a large stream is apparent, for the sediments are poorly sorted, commonly contain plant debris, etc. Evidently the shoreline in this region passed not far from the present boundary of distribution of these sediments. In the western and northwestern parts of the depression, the nearshore deposits consist of well-sorted sand, commonly glauconite-bearing.

The nature of sediments in the central section is at present unknown. An increase in the amount of fine-grained sediments observed in some areas from the periphery towards the center (Tabaga-Yakutsk region, region of the Viluy and Kempendyay rivers) indicates that the central section must contain mainly sand and silt or even silt and clay deposits.

In the central and latitudinal sections of the Verkhoyansk Range and Viluy depression, there is a broad zone of shallow-water, predominantly arenaceous sediments. The formation of these sediments is evidently due to the transportation by currents into the remoter parts of the basin of the sandy material brought to the southwestern edge of the basin by large streams flowing from the Aldan shield. It is also due to the erosion of islands inherited from the preceding epoch and partially submerged in the middle Liassic sea. In the north and east, the sandy tongue is bordered by a wide band of sand, silt and clay with finely-graded, flysch-like bedding. This zone is succeeded on the eastern slope by essentially agrillaceous sediments deposited mainly in the deeper areas of the basin.

The next stage, of Late Lias age, was marked by further deepening and widening of the basin. The erosion in the adjacent continental areas decreased considerably. The basin received mainly argillaceous material which spread over the entire Viluy depression. The sandy and silty sediments were deposited in the Late Liassic basin only in the areas nearest the source of the detrital materials, i.e., in the eastern part of the Tungusska-Viluy downwarp [2, 10] and on the southeastern margin of the Viluy depression.

An extensive contribution of detrital material from the southeastern part of the Aldan shield insured preservation of the general facies distribution at the juncture between the southeastern part of the depression and the western Verkhoyansk region (Fig. 3). The north-south tongue of essentially sandy sediments bordered in the north and east by sand, silt and clay deposits was inherited in its entirety by the Late Liassic basin. To the north and east, towards the open parts of the basin, the sand, silt and clay are succeeded by essentially agrillaceous sediments.

The clay and silt-and-clay deposits of the Verkhoyansk region have a high content of thinly dispersed organic matter. The abundance of organic matter resulted in the strong development of diagenetic pyrite and in an increased bitumen content. Light oils make up a large part of the bitumens (up to 50 percent of the total content). It should be

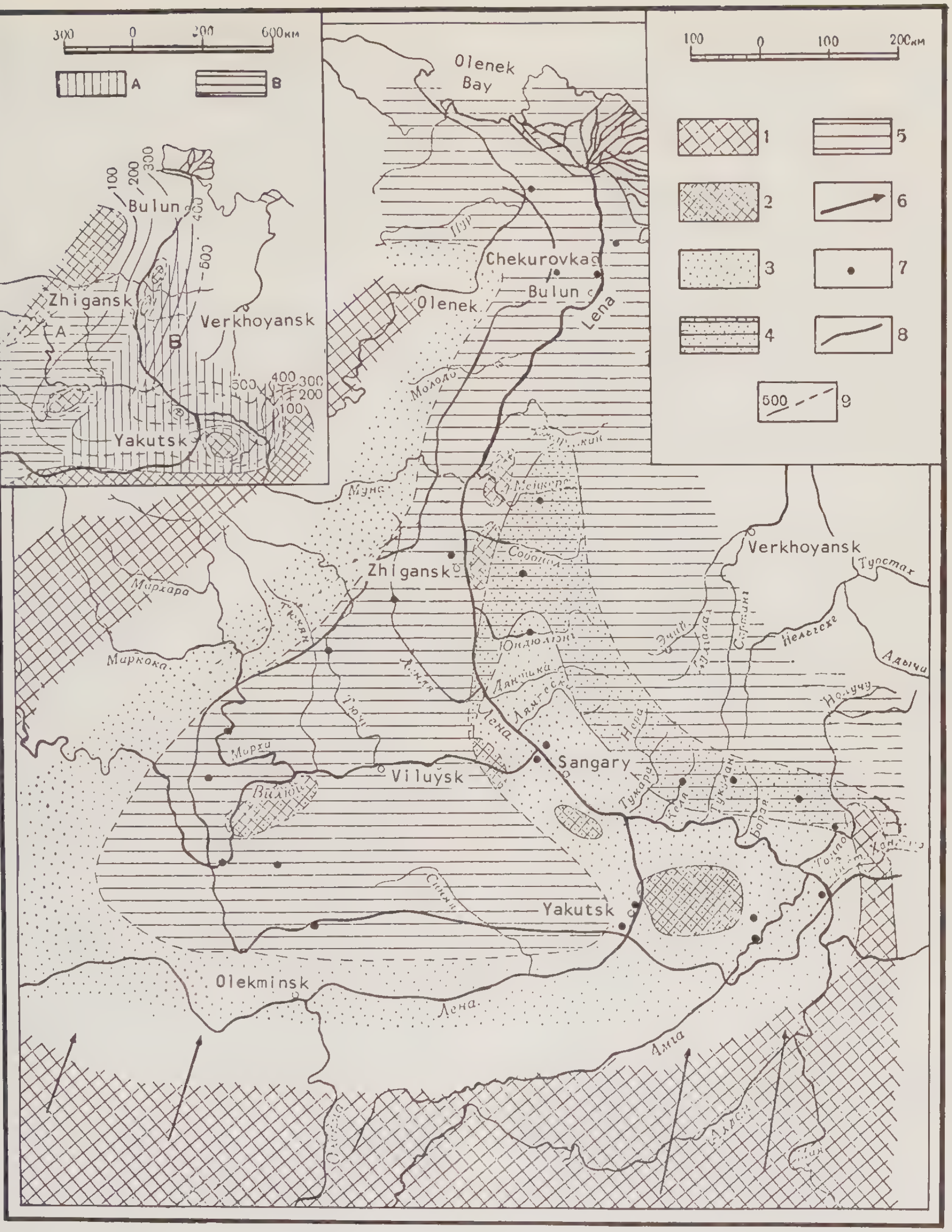

Fig. 3. Facies distribution during Late Lias.

1 -- Land; 2 -- outcrops of the ancient basement and areas of decreased sedimentation and erosion; 3 -- marine littoral and shallow water deposits, mainly sand; 4 -- sand, silt and clay of the relatively remote parts of the basin; 5 -- marine clay; 6 -- direction of sediment transport; 7 -- observation points; 8 -- limit of present distribution of Upper Liassic sediments; 9 -- isopachs on the silt and clay complex (J_1^{2+3}).

Terrigenous mineralogic provinces: A -- epidote-ilmenite-hornblende; B -- garnet-tourmaline-zircon.

noted that the conditions of deposition of these sediments in the Verkhoyansk region, the considerable rate and depth of subsidence, the marine regime and the abundance of organic material were very favorable for the formation of petroliferous facies.

The distribution of detrital mineral associations during the Middle and Late Lias was essentially the same as during the Early Lias. The difference in the mineralogy of the sediments of the Verkhoyansk region and of the eastern part of the depression disappeared almost entirely. Evidently the barriers separating these regions were largely leveled off by this time. The existence of some uplifts in the central section of the Verkhoyansk region is indicated only by the presence of shallow water, mainly sandy, sediments in the vicinity of Kitchan village and the Dyanushka River.

The maximum subsidences resulting in accumulation of sediments 500 m thick occurred in the central Verkhoyansk Range and apparently extended in a narrow band into the central area of the Viluy depression. The depression at this time was a slightly downwarped area filled with sediments not exceeding 250 m in thickness (Fig. 3).

The time of accumulation of the upper sandy complex (J_2). At the contact between the Lower and Middle Jurassic beds, sharp changes occurred in the environment of sedimentation, signalizing a turning point in the development of the Mesozoic basin. A new stage began in the history of the Viluy depression and the western Verhoyansk region, a prolonged regression accompanied by a gradual shrinking of the basin and a corresponding increase in the area of continental deposition.

At the beginning of the Middle Jurassic, large uplifts occurred in the southwestern source area and throughout a considerable part of the Viluy depression, which caused partial erosion of the previously deposited sediments. The most extensive uplift and erosion occurred in the southwestern part of the depression, the intensity of erosion decreasing gradually to the north and east. No signs of uplifts are recorded in the Aldan River and Verkhoyansk regions; the marine regime persisted there. Large-scale transport of detrital material to the Viluy depression began after the uplift. In the very beginning of the stage, coarse alluvial sands enriched in kyanite were deposited along the sides of the depression (Viluy, Markha and Sinyaya rivers and the Yakutsk region). In the eastern areas (Yakutsk) they were rather rapidly succeeded by marine littoral deposits.

Continental alluvial-lacustrine sediments continued to accumulate throughout the Middle Jurassic in the southwestern margin of the depression. Periodically, the shallow lake basins became bogs and thin peat beds formed in them (in the region of the Ygetta, Viluy and Kempendyay rivers). A band of littoral marine sand, sandy silt and, less commonly, clay formed in the bays, lagoons and shallow coastal lakes to the east (in the region of the Tyung, Markha, Amga rivers and in the vicinity of Yakutsk). In places the eastern areas of the region were invaded by the sea, and marine sand containing pelecypod shells was deposited. Along the slopes of the Aldan and Anabar massifs and also evidently in the central part of the basin, nearshore marine sediments accumulated. The sediments of the basin areas farther from the shore are also dominantly arenaceous. This indicates the extreme shallowness of the sea and possibly the presence of island chains in the Verkhoyansk zone and the adjacent part of the depression.

The Middle Jurassic epoch was marked by rather uniform subsidence and accumulation of sediments over 300 m in thickness both in the region of the Viluy depression and in the area adjacent to the Verkhoyansk region.

The time of formation of the coal-bearing complex ($J_3-Cr_1^{neoc+apt}$). The Late Jurassic epoch was marked by further reduction of the marine basin, retreat of the sea to the north and northeast and persistence of a marine regime only in the regions north of the Arctic Circle [16] and east of the divide of the present Verkhoyansk Range. Erosional and depositional processes of the early Late Jurassic changed the Viluy depression and the western Verkhoyansk region into an extensive plain slightly tilted to the north and northeast. Slight downwarpings enabled the sea to spread rapidly over this territory.

Late Jurassic history is divisible into two stages.

The first stage was characterized by an intensification of stream flow and increased delivery of detrital material to the basin. In the western part of the depression, mainly sandy sediments of the stream-channel type were deposited (Viluy, Kempendyay, Markha and other rivers). Within the marginal areas of the depression, the stream deposits merge with deltaic and possibly submarine stream channel deposits to the east. Periodically the facies of coastal lakes and barred lagoons, changed into marshes and filled with peat, were developed on a large scale (Kil'dyamtsy, Ytnyk-Kel' and other regions).

In the central part of the Viluy depression, at its junction with the Verkhoyansk

Range, marine littoral deposits with a great variety of facies characteristic of the transitional continental-marine environment were dominant. In the latitudinal and central areas of the Verkhoyansk Range, typical marine sediments were deposited. However, even this territory was occasionally emergent and large areas became peat-accumulating swamps. The normal marine regime was maintained north of the latitude of Zhigansk, and shallow water sand, silt and clay carrying marine Aucella fauna were deposited (Fig. 4).

The second stage, embracing the late Oxfordian and early Volgian time, was marked by a slight transgression and reduction in the deposition of clastic material. On the outer edges of the depression, the coal-bearing sediments were succeeded by marine sand with an Aucella fauna (Sytoginsk formation).

In the Late Jurassic epoch, major subsidences accompanying the upwarping of the Verkhoyansk geanticline and emergence of islands in the central part of the structure occurred in the west. The zone of maximum subsidence was localized in the central and latitudinal sections of the Verkhoyansk region and extended into the Viluy depression as a broad tongue. The sediments are of maximum thickness in the latitudinal and central sections (1, 000 m) (Chechuma and Tynkchan rivers area). In the depression the sediments are as thin as 800 to 850 m in the central parts and are sharply reduced to 200 to 250 m on the margins of the depression. Within the meridional section, the platform regime persisted; the downwarps were very slight and the thickness of the Upper Jurassic sediments does not exceed 150 m and diminishes to 50 m in the Kharaulakh Mountains (Fig. 4).

The Early Cretaceous epoch was characterized by further, gradual shrinking of the marine basin, retreat of the sea far to the north and final establishment of continental conditions throughout the territory at the end of the epoch. There are several stages in the history of this epoch. During the first stage, coinciding with the accumulation of sediments of the lower half of the Batylykh formation (Valanginian ?), essentially the same regime persisted in the Viluy depression and the western Verkhoyansk region as in the Late Jurassic.

During the second stage, represented by the upper Batylykh (Hauterivian–Barremian ?), the marine basin further diminished. As the sea retreated far to the north, alluvial and alluvial-lacustrine deposits became dominant. In connection with the general uplift, the contribution of the detrital material from neighboring lands increased greatly and thick deposits of sand became widespread. Actual marine conditions were preserved only north of Bulun.

The important feature of the Lower Cretaceous sediments is the sharp change in the detrital mineral association in the sediments of the eastern part of the Viluy depression and over the entire Verkhoyansk region. The zircon-garnet association which persisted through the Jurassic period gave place to the minerals of the epidote group, which are very widely distributed throughout the Verkhoyansk region. Throughout the Mesozoic the minerals of the "epidote association" came from the Baikal-Patomsk uplands, and it has been observed that in passing from the older to the younger Mesozoic sedimentary layers, the area of distribution of the epidote association was extended eastward. It would be natural to assume that such wide distribution of epidote and zoisite in the sediments of the Verkhoyansk region was related to increased deposition of the material from the southwestern source area. However, a detailed study of the essential and accessory minerals shows that there are two different associations enriched in epidote.

In the southeastern association, as shown by V. I. Murav'yev [12], the epidote is accompanied mainly by quartz and potash feldspars, and there is commonly a considerable amount of ilmenite and hornblende and a small amount of garnet (largely andradite), kyanite, staurolite, sillimanite and a number of other minerals.

In the eastern part of the depression and over the large Verkhoyansk territory, the epidote minerals are associated with abundant plagioclase, and, particularly, albite (constituting 60 to 65 percent of the rock). "Sieve structure" filled with inclusions of zoisite, less commonly of epidote and sericite is very common in the albite. The association is poor in accessory minerals. Besides epidote, zoisite and the ever-present allanite, there are biotite, garnet, sphene and sometimes apatite. All of these minerals, according to D. S. Korzhinskiy [6], are found in the schist of the ancient Stanovoy complex. The abundance of albite with "sieve structure," a characteristic constituent of the thick diaphthorites exposed now in the Stanovoi Range [9] is especially typical. There is no doubt that the detrital material brought to the Verkhoyansk region was derived from erosion of the ancient crystalline complex of the Stanovoy Range and possibly of the Aldan shield. In addition to being derived from a southern source, some of the detrital material came from the southwest. This is indicated by the presence of fresh pistachio-green epidote, birefringent andradite and orange-brown garnets distributed widely through the Jurassic and Cretaceous sediments of the western part of the depression.

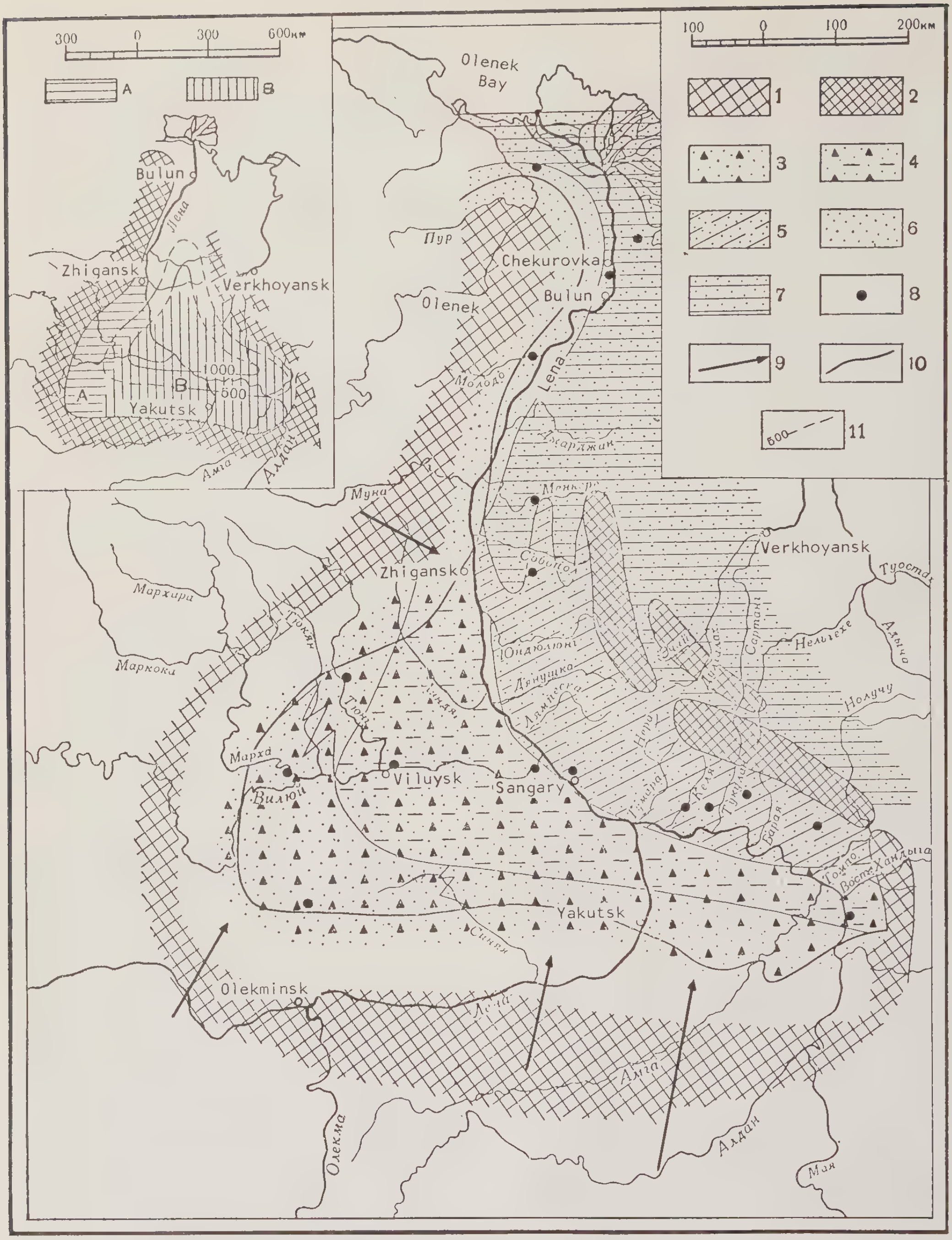

Fig. 4. Facies distribution during the Late Jurassic.

1 -- Land; 2 -- areas of diminished sedimentation and erosion; 3 -- mainly continental (alluvial, lacustrine), coal-bearing deposits; 4 -- mainly near-shore (deltaic, bay, lagoon, etc.) coal-bearing deposits; 5 -- near-shore marine, coal-bearing deposits, 6 -- near-shore marine sands; 7 -- sand, silt and clay of the open sea; 8 -- observation points; 9 -- direction of sediment transport; 10 -- limits of the present distribution of Upper Jurassic deposits, 11 -- isopachs on the J_3 beds.

Terrigenous mineralogic provinces: A -- epidote-ilmenite-hornblende; B -- zircon-apatite-garnet.

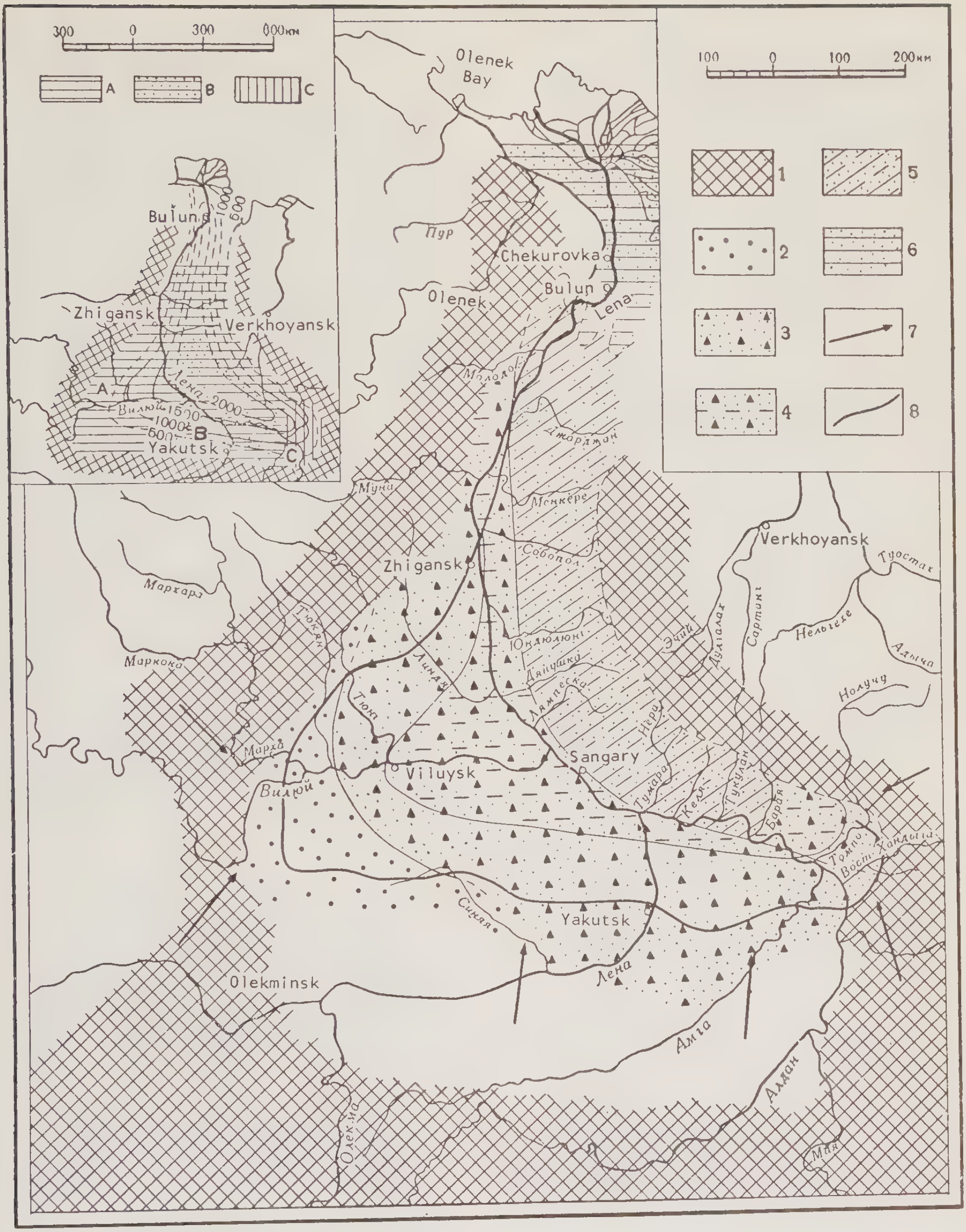

Fig. 5. Facies distribution in the Early Cretaceous (first half).

1 -- Land; 2 -- alluvium, mainly sandy; 3 -- mainly continental (alluvium and lake beds) coal-bearing sediments; 4 -- mainly near-shore (deltaic, bay, lagoon and lake) coal-bearing deposits; 5 -- mainly near-shore marine coal-bearing deposits; 6 -- marine shallow-water sand and silt; 7 -- direction of sediment transport; 8 -- limits of the present distribution of Lower Cretaceous sediments.

Terrigenous mineralogic provinces: A -- epidote-ilmenite-hornblende; B -- epidote association (with abundant sodic plagioclase); C -- zircon-apatite-garnet.

The third stage of the Early Cretaceous epoch was the time of accumulation of the Eksenyakh formation (Cr^{apt}). At this time the region was completely emergent. The Viluy depression and the Verkhoyansk region formed one vast alluvial plain drained by numerous streams depositing uniform sandy sediments. The abundant detrital material crossed the coal-bearing facies in the northern regions. The main sources of detrital material were as before. However, hornblende was added to the minerals present in the Batylykh formation.

During the Early Cretaceous epoch, differential movements occurred in the Verkhoyansk region and the adjacent areas of the depression [14]. The Verkhoyansk geanticline continued to rise. The greatest marginal downwarping occurred during the Early Cretaceous epoch. Not only did the rate of subsidence increase but so did the area of downwarp as well; and the entire meridional section of the Verkhoyansk region, which during Upper Jurassic time had undergone only very slight subsidence, became involved in the zone of greatest downwarping. Stretches of the zone of maximum subsidence filled with sediments up to 2,500 m in thickness parallel to the trend of the Verkhoyansk geanticline and merging with the Vilui depression in the central section, where the thickness of sediments gradually decreases (to 1,000 m in the central areas and 200 to 250 m on the limbs of the depression; Fig. 5).

The end of the Early Cretaceous and the Late Cretaceous were times of deposition of the alluvial, kaolinized sand complex which terminates the Mesozoic cycle. This period began in Albian time (Khatyryk time) and continued through the entire Late Cretaceous.

This period of time was marked by changes in the conditions of sedimentation in the Verkhoyansk region related to important events in the development of more easterly areas. The northeastern geosynclinal region was subjected to intense orogenic movements accompanied by regional faulting and intense volcanic activity, which initiated the final stage in the folding of the Verkhoyansk-Kolyma geosyncline [15]. The Verkhoyansk region became a mountain range.

Between Aptian and Albian times, brief uplifts occurred in the region of the Viluy depression determining the conditions of sedimentation for the subsequent period of downwarping. The data are at present insufficient for the reconstruction of the configuration and plan of distribution of the uplifted areas. Indirect evidence suggests that the largest uplifts occurred in the eastern part of the depression, particularly in the zone of buried ledges of the ancient crystalline basement which were subjected to new movements associated with the strong orogenic activity in the east. The effects of the intense volcanism in the east were also felt at the junction between the Viluy depression and the latitudinal section of the Verkhoyansk region. A convincing proof of this lies in the presence of dacite tuff and sandy tuff (about 4 m thick) found by the author in the Namtsinsk borehole. The movements of ancient horsts favored the rise and extension of magma. It is very probable that volcanic flows were considerably greater at the junction of the latitudinal section of the Verkhoyansk region with the platform but are now concealed under Upper Cretaceous and Tertiary rocks widespread in the region between the Lena and the Aldan rivers.

The general uplift of the Verkhoyansk region shifted the zone of maximum subsidence westward, into the region of the Viluy depression proper which, even at that time, was probably no longer a simple syncline. In Khatyryk time (Albian) the zone of downwarping was probably broken up into separate areas subjected to more or less intense subsidence. Very likely, these differential movements later initiated the evolution of the Later Cretaceous basins within the Viluy depression [5]. During the accumulation of the Khatyryk formation and afterwards throughout the Late Cretaceous epoch, alluvial sands were deposited almost exclusively, only occasionally alternating with lacustrine silt and clay and layers of coal and lignite.

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COMPARATIVE DIAGRAM

OF THE UPPER TRIASSIC, JURASSIC AND CRETACEOUS DEPOSITS

OF THE WESTERN SLOPES OF THE VERKHOYANSK RANGE AND THE VILYUY DEPRESSION

TRANSLATOR'S NOTE

The following four pages comprise a fractional four-part representation of a correlation chart which was attached to the original as a single unit. In the original, A, B, C, and D components of this single unit were presented in the following manner:

A	C
B	D

A

WESTERN SLOPES OF THE VERKHOYANSK RANGE

AGE			LITHOLOGIC-GENETIC COMPLEXES (FORMATIONS)		LATITUDINAL SECTION - Uyana, W. Gradyga, Ybykan, Kolya Rivers	CENTRAL SECTION Chechuma R., Sangary and Kitchan' Channels, Lyam Peska, Dyanushka, and Yundyulyung Rivers	MERIDIONAL SECTION Begidzhan, Sobopol, Menkgere Rivers
UPPER CRETACEOUS	Datian		COMPLEX OF ALLUVIAL, KAOLINIZED SANDS IN A SUPERIMPOSED SYNCLINE	STAGE OF GENERAL UPHEAVAL	DEPOSITS UNKNOWN		
UPPER CRETACEOUS	Senonian						
UPPER CRETACEOUS	Turonian						
UPPER CRETACEOUS	Senoman						
LOWER CRETACEOUS	Albian						
LOWER CRETACEOUS	Aptian	SANGAR SERIES	SANDY-ALLUVIAL COMPLEX	STAGE OF REGRESSION	EKSENYAKH FORMATION 500 m Sands and sandstones with occasional interbedded siltstones, silty clays and thin coal seams. Large carbonate concretions. Principally continental alluvial deposits. In the latitudinal sections, thin layers of conglomerates with quartzite pebbles, effusives and rocks from the Verkhoyansk complex. Onychiopsis elongata, Contopteras onychioides. HORNBLENDE, EPIDOTE. % of Heavy Fraction > 2-2.25		Coal-Bearing Deposits represented by interchanged sandstones and riders of siltstones, argillites and coals. EPIDOTE, GARNET, BIOTITE, APATITE above HORNBLENDE
LOWER CRETACEOUS	Barremian		COAL-BEARING COMPLEX		BATYLYKH FORMATION , 2,000 m In the lower half of the cycle there is an interchange of well-sorted sandstones with patches of interchanged siltstones and argillates. Above, the sandstones are more predominant and not as well-sorted. In the latitudinal section gravels appear, the pebbles of which are of metamorphic rocks and acid effusives. The coals alternate with riders (seams), rarely with sandstones. The composition of the sandstones is feldspar-quartz, predominantly fresh, acidic plagioclase, often with epidote. The cement is chlorite, laumontite (calcium zeolite) and carbonate. Large sandy-carbonate concretions. Environment of the first half -- littoral-marine; the second -- primarily continental. Cladophlebis lenaensis, cl. argurula, Coniopteris barejensis, etc. % of Heavy Fraction = 2%. EPIDOTE, GARNET (Rose, sometimes brown or orange) BIOTITE, APATITE, ORTHITE In the latitudinal section, layers rich in GARNETS		
LOWER CRETACEOUS	Gotterivian						
LOWER CRETACEOUS	Valanginian						

B

UPPER JURASSIC	Volgan Kimeridgian Oxford Callovian	CHECHUM SERIES	COAL-BEARING COMPLEX	STAGE OF REGRESSION	**MOOL' FORMATION** 900-1,000 m Interchanged sandstones with siltstones, argillites and coal seams. Sometimes flysch-type interstratification. Well-sorted clastics. Cement of sandstones -- chlorite -- hydrolis micaceous. Composition of sandstones -- quartz-feldspar; rich in fresh, acid plagioclase. Strong calcification of facies. Cladophlebis haiburensis, clad. argutula. Abundance of GARNET, CHLORITE, BIOTITE, ZIRCON, APATITE. **TYNKYCHAN FORMATION** 400 m Interchange of thick riders of rose sandstones with secondary riders of siltstones, argillites and coals. Well-sorted clastics. Characterized by siderite crystals in the ss. Cement -- hydrous mica and calcite. Littoral-marine. Baiera universis Equisetites angar. ZIRCON, GARNET, CHLORITE, BIOTITE	Complex of interchanged riders of sandstones with riders of interstratified siltstones, argillites and coals. LITTORAL-MARINE ENVIRONMENT Cladophlebis Aldanensis Vachr. Cladophlebis argutula Raphaelia Prinadii Vachr. Coniopteris gracillima Coals thickening toward the north. GARNET, ZIRCON CHLORITE, BIOTITE, APATITE	Complex of interchanged riders of sandstones with riders of siltstones and argillites, sometimes with thin coal seams dying out toward the north. Marine, rare Littoral-Marine facies. Fauna, Aucella. GARNET, ZIRCON, ORES, MICAS, APATITE, EPIDOTE
MIDDLE JURASSIC		BAYLYK SERIES	SANDSTONE COMPLEX	INITIAL STAGE OF GENERAL REGRESSION	**UPPER - YBYKAN FORMATION** 200 - 250 m Sandstone series of fine-grained, well-sorted shallow-water zone of a marine basin with Eumorphetis Cenaensis. ZIRCON, GARNET, TOURMALINE occasionally TITANITE, EPIDOTE	Principally fine- and medium-grained marine sandstones. Similar to those below. ZIRCON, GARNET, TOURMALINE, occasionally TITANITE	Principally sandstones. Eumorphotis lenaensis, Inoceramus retrosus, etc.
LOWER JURASSIC	Upper Lias Middle Lias Lower Lias	BAYLYK SERIES	SILTSTONE-CLAY COMPLEX	STAGE OF MAXIMUM TRANSGRESSION AND STABILIZED BASINS	**LOWER - YBYKAN FORMATION** 300 - 600 m Interchange of ten flysch-type, dark gray and black siltstones, siltstone shales and sandstones. Rich in pyrites; increasing bituminous content. Pseudomonotis Tiungensis, Amaltheus margaritatus, Eumorphotis marchaensis. ZIRCON, GARNET, TOURMALINE	Shallow-water, marine sandstones with a few layers of siltstones and argillites with belemnites and pelycopods. Texture: "shallow-water ripple" ZIRCON, GARNET, TOURMALINE, occasionally CHLORITOID, containing TITANIUM	Interchanged sandstones and siltstones, often dark-colored. Dactylioceras gracile (Simp.). Tancredia stubendorfii Schm., Eumorphotis marchaensis
UPPER TRIASSIC	Norilskiy Retskiy Carnian	BAYLYK SERIES	LOWER CONGLOMERATE-SANDSTONE COMPLEX	STAGE OF DEVELOPING TRANSGRESSION	**GRADYGA FORMATION** 300 - 800 m Littoral sandstones with subordinate interstratification and lenses of conglomerates of the type deposited under water. Well-sorted clastics. Quartz-feldspar composition. Characterized by highly-developed, quartzite-like structures in the sandstones. At the top (in the middle and meridional sections) layers of fine gravels, principally of quartz conglomerates. ANATASE, BROOKITE, TOURMALINE (often blue), ZIRCON, GARNET, occasionally CHLORITOID, in the latitudinal section, an absence of GARNETS, PYRROHOTINES **SORODOGIN FORMATION** 500 - 700 m Littoral-marine, light-colored sandstones with a few layers of greenish-gray siltstones. Quartz-feldspar composition, occasionally with effusive clastics. Thickness of the base conglomerate to 12 m with pebbles of igneous and metamorphic rocks ANATASE, BROOKITE, TOURMALINE, ZIRCON, GARNET, MICA, at the base EPIDOTE		At the base, occasional conglomerates with pebbles of quartz, limestones and basement rocks

C

<table>
<tr><th colspan="2" rowspan="3">THE CENTRAL, MOST-FOLDED SECTION OF THE VILYUY DEPRESSION

(Vilyuy region, NAMTSY WELL)</th><th colspan="4">PLATFORM SLOPES OF THE VILYUYSK DEPRESSION AND THE LONGITUDINAL SECTION OF THE FLEXURE</th></tr>
<tr><th colspan="2">South Wall of the Vilyuy Depression and East Slopes of the Ardansk Shield</th><th>West Wall of the Vilyuy Depression</th><th>North Wall of the Vilyuy Depression and the East Slopes of the Anabar Massif</th></tr>
<tr><th>Lower Reaches of the Aldan River</th><th>Irkutsk Region, Sinyaya River</th><th>Vilyuy River region (Central channel) Markha R., Ygetta R.</th><th>ZHIGANSK REGION</th></tr>
<tr><td rowspan="3">VILYUYSK SERIES</td><td>LINDEN FORMATION 100 m
Sands, highly kaolinized, with interbedded sandy clays and lignites; lenses of conglomerate. Sands principally of quartz composition.
ILMENITE (to 80%), GARNET</td><td colspan="4" rowspan="3">DEPOSITS MISSING</td></tr>
<tr><td>TIMERDYAKH FORMATION 800 m
Sands and friable, cross-bedded, kaolinized sandstones with interbedded sandy clays with amber, lignite. Lenses of conglomerate. Alluvial deposits. GARNET, KYANITE, ILMENITE, EPIDOTE</td></tr>
<tr><td>KHATYRYK FORMATION 200 m
White kaolinized sands with interbedded clays with amber and thin coal seams. At Namtsy Well, at the base -- 4 m of grano-diorite tufaceous sands.
KYANITE, GARNET, ILMENITE</td></tr>
<tr><td rowspan="2">SANGAR SERIES</td><td>EKSENYAKH FORMATION 350 m
Sandstones with secondary interbedding of siltstones, clays, occasionally coals.
HORNBLENDE, EPIDOTE, GARNET</td><td>EKSENYAKH FORMATION
Sandstones with large carbonate concretions. Coniopteris onychioldes Ginkgo adiantoides.
EPIDOTE GARNET BIOTITE</td><td rowspan="2">250 m
KANGALAS-TYPE COAL SERIES
Cyclic interchange of sandy riders with riders usually interstratified with thick coal.
Two cycles are identified: in the lower, the main minerals are:
EPIDOTE, GARNET
In the upper;
HORNBLENDE, EPIDOTE</td><td rowspan="2">Series of Continental Coal Deposits
Thick coals in the Jurassic Deposits
EPIDOTE, ILMENITE, HORNBLENDE
In the upper, T_3 strata, riders of highly concentrated APATITE</td><td rowspan="2">500 m
Cyclic interchange of sandy riders with riders of interstratified siltstones, clays and coals. % heavy fractions >2.5 - 3.
EPIDOTE, BIOTITE, CHLORITE, APATITE, GARNET, HORNBLENDE</td></tr>
<tr><td>BATYLYKH FORMATION
In the lower half, interchange of sandstones with siltstone-clay riders with coal; in the upper half, principally sandstones, feldspathic-quartzitic.
EPIDOTE, GARNET CHLORITE, BIOTITE</td><td>BATYLYKH FORMATION
Interchange of sandstones with riders of the usual siltstones, orgillites and coal. Cladophlebis argutula Taeriopteris amurensis. Ctenis, Tyrmia.
GARNET, APATITE TITANITE</td></tr>
</table>

D

CHECHUM SERIES	650 - 700 m Cyclical interchange of sandy riders with riders of siltstones and coals. Cyclical feature complex. Sandstones and siltstones well-sorted. The complex texture of the muds, rates of silting, indicate a "shallow water ripple" type of deposition. Littoral environment. Raphaelia diamensis, Cladophlebis aldanensis Vachr. GARNET, ZIRCON, CHLORITE, BIOTITE, APATITE, (at the top of the Vilyuy Well, EPIDOTE)	200 - 13 m SYTOGIN FORMATION Marine, fine-grained sandstones, siltstones and clays. Aucella Rugosa, A. mosquensis, A. Cindstroemi. 400 - 500 m DZHASKOY FORMATION Cyclic interchange of sandy riders with siltstone-argillite riders containing coal. Raphaelia diamensis, Cladophlebis aldanensis. GARNET, ZIRCON BIOTITE, APATITE	300 - 350 m KIL'DYAM-TYPE COAL SERIES Cyclic interchange of sandstone riders with riders usually interstratified with thick coal strata. Three macro-cycles are identified. Poorly-sorted sands and sandstones; kaolinite clays in the lower coals, montmorillonite in the middle coal riders. Continental, above continental-littoral environments. GARNET, ZIRCON ILMENITE, BIOTITE, APATITE, TITANITE	Series of Continental Coal Deposits Thick coals in the Jurassic Deposits EPIDOTE, ILMENITE, HORNBLENDE In the upper, T_3 strata, riders of highly concentrated APATITE	30 - 60 m SYTOGIN FORMATION Marine, fine-grained sandstones, siltstones and clays. 150 m DZHASKOY FORMATION Cyclic interchange of sandy riders with riders interstratified with coal. Three cycles are identified. Raphaelia diamensis, Baiera annartii. EPIDOTE, GARNET, HORNBLENDE, ILMENITE
	400 m Sandstones with layers of siltstones. At the base of the Namtsy Hole section, small-pebbled conglomerates.	250 m Shallow-water, marine sandstones. Eumorphotis Cenaensis, Inoceramus tetrorsus, etc. ZIRCON, GARNET, TITANITE, EPIDOTE	YAKUT FORMATION Sandstones with layers of siltstones and clays of the littoral type. ZIRCON, GARNET MICA, TITANITE At the base, coarse sands with DISTHENE	300 m Alluvial-delta sands and sandstones, above with layers of siltstones and thin coal seams. EPIDOTE, HORNBLENDE, ILMENITE	300 m Fine-grained marine sandstones with layers of siltstones. Characteristic of limestones, star-shaped concretions. Inoceramus retrorsus, Eumorph. Cenaensis. EPIDOTE, GARNET, MICA
	DEPOSITS NOT EXPOSED	TABAGIN FORMATION Shallow-water sandstones with layers of siltstones and siltstone-clays, sometimes with pyrites. Eumorphotis marchaensis. MARINE LITTORAL SANDSTONES Amaltheus margaritatus, Karpax, Myophoria Caevigata, Pseud. tungentis ZIRCON, GARNET, LEUCOCSIN	Belemnites of brevis. MICA, GLAUCONITE	70 - 100 m Primarily clay sediments with layers of sandy limestones, abundant pyrite. Leda acuminata, etc. Marine, fine-grained limestones. Well-sorted sandstones and glauconites. Pseud. tiungensis Harpax Caevigatus, etc. EPIDOTE, HORNBLENDE, ILMENITE	230 m Interchanged clays, siltstones and fine-grained sandstones of marine shallow-water zones. Pyrite pebbles. Pseud. tuingensis, Leda acuminat, Leda jacutica, etc.
		UKUGUT FORMATION Sandstones with conglomerate layers; deposits laid down at river mouth. Poorly-sorted. Cement of clays generally kaolinized. GARNET, to 88%, ZIRCON, TOURMALINE (Disthene, Staurolite)		200 - 30 m Sandy-conglomerate alluvial-river deposits. EPIDOTE, HORNSTONE, BLENDE, ILMENITE	
		DEPOSITS UNKNOWN			

STRATIGRAPHY OF THE JURASSIC AND CRETACEOUS DEPOSITS OF THE UPPER BASIN OF THE AMUR RIVER

by

M.S. Nagibina

This paper presents a new stratigraphic subdivision of Jurassic and Cretaceous freshwater-continental deposits of the upper basin of the Amur River, based on the author's observations and on the lithologic and paleontologic material collected by other investigators.

All local stratigraphic sections worked out by different geologists for individual areas of the Upper Amur region are correlated and unified.

* * * * *

HISTORY OF INVESTIGATIONS

Mesozoic sediments are widespread in the upper basin of the Amur River. They lie with sharp angular unconformity on the eroded surface of Middle Paleozoic strata in deep synclines or in small, superposed folds on Lower Paleozoic and older metamorphic rocks.

The wide distribution of Jurassic rocks in the upper Amur region was noted by F.B. Schmidt in the 60's of the last century (1869) in the report of the physical section of the Siberian Expedition. The Jurassic age of these sediments was established on the basis of plant imprints contained in them.

In 1927-1928, A.I. Khlaponin, A.A. Leontovich and V.D. Prinada [1], while mapping at a scale of 1:500,000 in the upper course of the Amur River, found marine fossils and plant imprints which, according to the determinations by O.M. Kichigina and V.D. Prinada, are of Early and Middle Jurassic age.

In the 1930's, as a result of more detailed geologic mapping in the upper basin of the Amur River (N.P. Savrasov, V.Z. Skorokhod and others), the next step in the study of these Mesozoic sediments was taken and they were divided into stratigraphic units of different ages.

The results of investigations made in 1941 were published by Skorokhod in a large compilation on the geology of the Far East [9]. The Mesozoic deposits of the upper Amur region were divided by him into two complexes, the marine deposits (Bureya formation) and the freshwater-continental deposits (Nikansk formation) and further subdivided into the following units (base to top):

1) the basal conglomerate and coarse-grained sandstone, 30 m in thickness;

2) Inoceramus sandstone and sandy shale, 600-650 m thick;

3) interbedded sandstone and shale, 1100 m thick;

4) Gervillia sandstone and shale, 420 m in thickness; and

5) Modiola and cross-bedded sandstone, 1550 m thick.

Fossil marine faunas were collected from all of these units and this enabled Skorokhod to assign the first and second units to the Lower Jurassic, the third and fourth, to the Middle Jurassic and the fifth, to the Upper Jurassic. The total thickness of marine strata, as given by him, is 3,750 m.

The marine Jurassic beds are overlain conformably and with gradational contacts by continental and lagoon sediments of the Nikansk formation (base to top) divided into:

1) lower Nikansk formation, composed of sandstone with inclined bedding and layers of

sandy shale 1000 m thick;

2) middle Nikansk marine conglomerate-shale sequence, 350 m in thickness; and

3) upper Nikansk sequence of graywacke with shale and coal in the upper part, 1500 m thick.

The total thickness of the Nikansk formation is 2850 m.

The age of the Nikansk formation was determined by Skorokhod as Early and Late Cretaceous. On the basis of his study of fossil plants of Eastern Siberia and of Eastern Transbaikalia and the Upper Amur region in particular, Prinada [7, 8] challenges Skorokhod's conclusions as to the age of the coal-bearing beds of the upper Amur region and maintains that their correlation with the Nikansk formation of the southern Primor'ye is erroneous because the plant assemblages from these two formations are different. Prinada refers the coal-bearing beds of the upper Amur region to the Late Jurassic, the age of the volcanic extrusive-sedimentary formation of Eastern Transbaikalia.

During the past 20 years considerable attention has been given to the study of the upper part of the Mesozoic freshwater-continental, coal-bearing sediments. Geologic mapping has been done in various regions where these deposits are found, in order to determine their coal content. Among such investigations are the works of P.F. Popov (1932), N.P. Savrasov (1933), B.A. Ivanov (1938), S.S. Dobrynin (1941), V.D. Prinada (1946), N.A. Brumel' (1948, 1949), A.I. Arkhangel'skiy (1950, 1951), D.M. Sayapina and R.M. Tonoyan (1952), E.E. Krasninskaya (1954), N.E. Slastenova (1955) and others. Each of these authors constructed a stratigraphic section of the Mesozoic coal-bearing sequence for his own small area of the upper Amur region, using numerous local formation names. In the course of a regional structural study which the writer conducted over the past four years, she studied Mesozoic deposits in different localities of the region and made many correlations. These investigations made it possible to refine the stratigraphy of marine Jurassic deposits previously worked out by Skorokhod and to construct a new stratigraphic section for the freshwater-continental deposits of the upper Amur River, partly on the basis of personal observations and partly through correlation of all local stratigraphic sections published by previous investigators.

JURASSIC MARINE AND LITTORAL-CONTINENTAL DEPOSITS

Jurassic marine sediments are widespread in the upper Amur basin. Their presence here is proved by paleontologic studies made in the 1930's by A.I. Khlaponin, N.P. Savrasov, A.A. Kirillov and others, although these have been only partially confirmed in recent years.

The presence of marine Jurassic sediments in the basin of the Zeya River can be accepted only tentatively if the unfossiliferous sand and shale underlying the coal-bearing formations and lithologically very much like the marine Jurassic of the upper Amur River are referred to the Jurassic.

The marine Jurassic sediments of the upper Amur River are exposed (from west to east) in a belt trending northeast from the confluence of the Shilka and Argun Rivers to the Omutnaya River, crossing the lower course of the left tributaries of the Amur, Amazar, Urka, and Tomach Rivers and the upper course of the Ignashikha River, and forming the so-called Amazar downwarp. To the east, marine Jurassic deposits are exposed in a wider belt with the same trend, stretching from the valley of the Amur into the lower course of the Ol'doy River, into the basin of the Great Never River and, still farther eastward, into the basin of the Kerak River (right tributary of the Urkan River) forming the large Oldoy and Kerak downwarps. East of the mouth of the Great Never River these deposits stretch in a band with a northwest, nearly north-south trend into the upper basins of the Osezhina and Burinda Rivers (Fig. 1).

The most complete section of marine Jurassic sediments is on the northwest limb of the large Ol'doy downwarp where it was studied by the writer in the good exposures on the left bank of the Amur River from the Omutnaya River to Ul'duchinskiy Island and by A.A. Kalinovskiy (1952) in the basin of the Bol'shoi Never River (Fig. 2). According to our data, the marine Jurassic section of the southwestern part of the Ol'doy downwarp is as shown in Fig. 2 (base to top):

I. The basal beds. Marine Jurassic sediments lie transgressively with sharp angular unconformity on the deeply-eroded surface of folded, Middle Paleozoic rocks and the granitoids intruded into them.

The basal Jurassic beds are very varied in composition, which is governed almost entirely by the composition of the underlying older rocks.

According to Skorokhod [9], Kalinovskiy

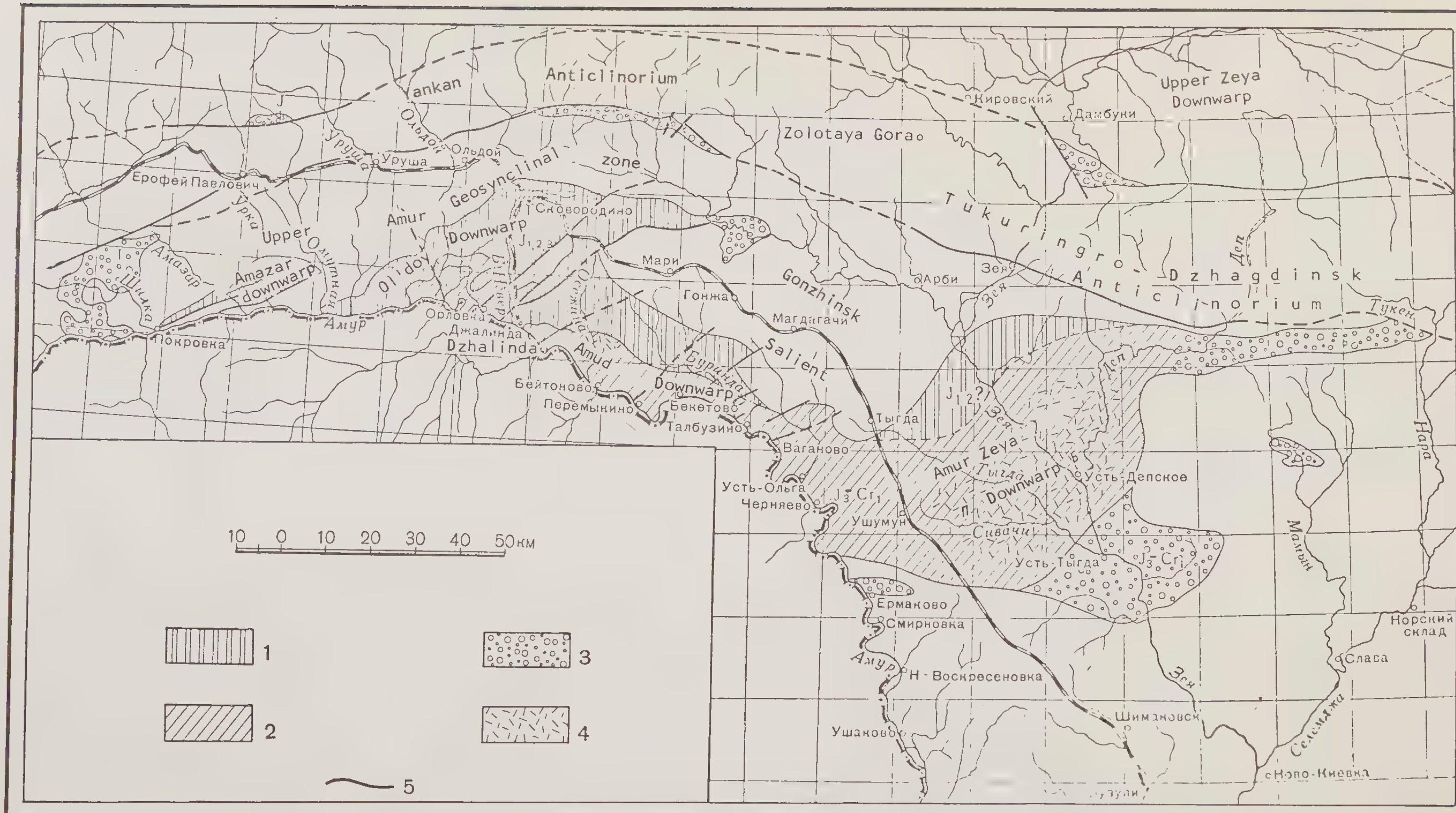

Fig. 1. Distribution of Jurassic and Cretaceous deposits in the Upper Amur region.

1 -- Jurassic marine deposits (J_1, J_2, J_3), 2 -- Upper Jurassic and Lower Cretaceous freshwater-continental deposits, 3 - Jurassic and Upper Jurassic-Lower Cretaceous (J_3-Cr_1) continental, mainly coarse-grained deposits, 4 -- terrigenous deposits with beds of tuff and sandy tuff, 5 -- faults

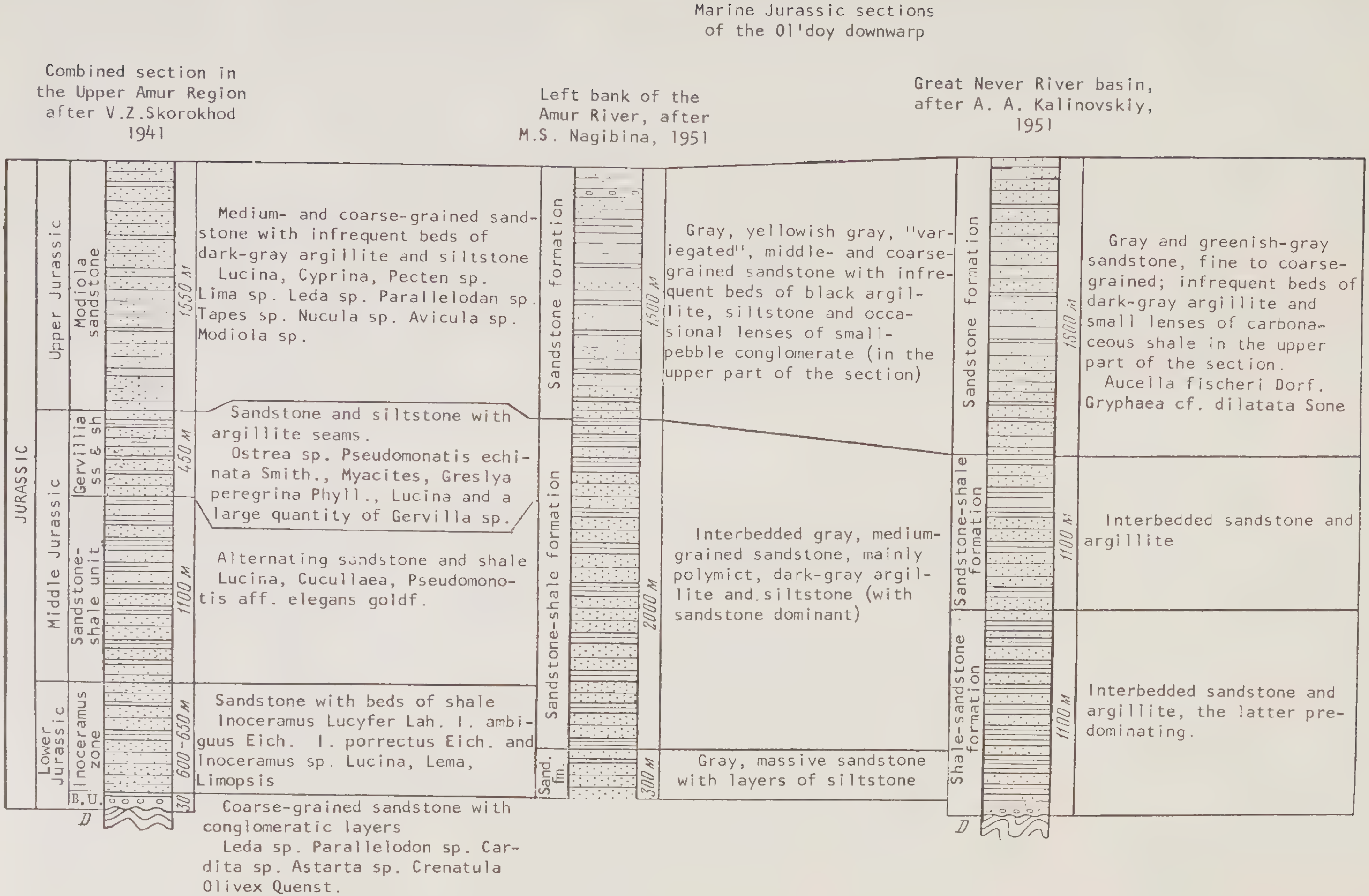

Fig. 2. Correlation of Lower and Middle Jurassic marine deposits of the Upper Amur region.

(1952) and others, the base of the Jurassic sediments in the Ol'doy syncline, lying directly on the Devonian rocks, is a thin layer (15 to 20 cm thick) consisting of folded Devonian rocks cemented by argillaceous-arenaceous material. Above it lie sandstones containing well-rounded pebbles of Paleozoic rocks. The upper beds of the basal unit are coarse-grained sandstone with calcareous cement and thin layers and lenses of conglomerate. From the basal unit, Skorokhod collected a marine Liassic fauna with Crenatula olivex Quenst., Astarta sp., Cardita Parallelodon sp. and Leda sp.

The thickness of the basal beds is about 30 m.

II. The lower part of the marine Jurassic section (sandstone formation). In the exposures on the banks of the Amur River, the basal unit is absent and the lower part of the marine Jurassic section, exposed on the left bank of the river below the mouth of the Omutnaya River, consists of the following rocks (bottom to top):

1. Gray massive sandstone with quartz-sericite and quartz-sericite-carbonate cement and occasional two- to three-meter layers of dark-gray sandy shale. Thickness -- 250 m.

2. Interbedded gray fine-grained sandstone and sandy shale. Thickness -- 40 m.

3. Middle part of the marine Jurassic section (sandstone-shale formation).

4. Gray massive sandstone analogous to those in group one. Thickness -- 250 m.

5. Interbedded gray medium-grained sandstone with black shale. Individual beds are 1 to 2 m thick. Thickness -- 150 m.

6. Gray coarse-grained massive polymict sandstone. Thickness -- about 180 m.

7. Gray medium-grained polymict sandstone 20-30 m thick containing layers of black shale 2 to 3 m thick. Thickness -- 180 m.

8. Gray massive medium-grained sandstone, locally with poorly developed stratification. Thickness -- 100 m.

9. For 1.5 km. along the left bank of the Amur River there are no outcrops (near the village of Sgibnevo). The same sandstone as in group 8 with the thickness of 350 to 400 m. Outcrops are absent for 2 m.

10. Interbedded dark-gray shale and gray fine-grained sandstone. Thickness -- 50 m.

11. Dark-gray shale interbedded with gray sandy shale, fine-grained sandstone and carbonaceous shale. The thickness of individual beds is 1 to 2 m. The shale contains poorly preserved plant imprints. Thickness -- 50 m.

12. Gray massive medium-grained sandstone (?). Thickness -- 50-60 m.

13. Gray sandy shale interbedded with layers of black shale 1 cm to 3 m in thickness. Thickness -- 100 m.

14. Interbedded sandy shale and sandstone with infrequent 1- to 2-meter beds of black shale. Thickness -- 100 to 150 m.

15. Interbedded fine-grained sandstone and black shale. The latter predominate in the section. Thickness -- 100 to 150 m.

16. Higher in the section the alternation of gray sandstone and black shale continues. In the upper part of the section the sandstone begins to predominate.

The thickness of the lower sequence is several hundred meters.[1]

III. The upper part of the marine Jurassic section (upper sandstone formation).

17. A sequence of massive medium-grained and coarse-grained sandstone with infrequent layers (0.5 to 1 m) of black sandy shale. The sandstones are gray, yellowish-gray, "variegated," and locally contain small lenses of coarse-grained sandstone and small pebble conglomerate. Layers of argillaceous sandstone and shale are irregularly distributed among the sandstone beds.

Within the sandstone sequence, near to the upper part, there is a rather thick (100 to 150 m) group of interbedded sandstone and shale with the latter dominant. Locally, within this group there are lenses and thin layers of carbonaceous shale. In some places the sandstones are almost free of shale and sandy shale whose thickness does not exceed 0.30 m. The thickness of the upper sandstone formation is 1500 m.

The total thickness of Jurassic sediments is about 4000 m.

The three parts of the section are conformable and have gradational contacts. The lower part corresponds to Skorokhod's Inoceramus zone, in which he found: Inoceramus porrectus Eichw., I. lucifer Lah., I. ambiguus Eichw., I. ussurensis Voronetz,

[1] The rocks are greatly dislocated. Measurements of thickness are difficult.

Lucina sp., Lima sp. and Limopsis sp.

The Inoceramus ambiguus Eichw. and Inoceramus porrectus Eichw. are found in the Aalenian deposits of the Far East and Northern Yakutia.

The middle part of the marine Jurassic section (interbedded sandstone and argillite) corresponds to the interbedded sandstone and shale and the Gervillia unit of Skorokhod [9]. From the first of these he collected Pseudomonotis aff. elegans Goldf., Cuculeaea sp. and Lucina sp., and from the second, Pseudomonotis echinata Smith, P. aff. elegans Goldf., Myacites sp. and numerous Gervillia sp. The faunal assemblage as a whole indicates the Middle Jurassic age of the beds. The species Pseudomonotis echinata Smith is found in the Bathonian sediments of the Crimea, Western Turkmenia and in the upper Bajocian of the Mangyshlak peninsula.

The upper part of the Jurassic deposits (upper sandstone formation) corresponds to the Modiola and the cross-bedded sandstone units of Skorokhod, in which he found Modiola sp., Lucina, Ciprina, Pecten sp., Lima sp., Leda sp., Parallelodon sp., Tapes sp., Nucula sp. and Avicula sp. This list contains no specifically determined forms. The faunal assemblage indicates only that the beds are Jurassic.

In 1951, Kalinovskiy found the Upper Jurassic fossils Aucella fischeri Dorf. and Gryphaea aff. dilatata Sone in the coarse-grained sandstone near the top of the upper part of the section on the right bank of the Great Never River, 6 km below the mouth of the Oshurkovka River. Unfortunately, it is not certain that the forms were accurately named; Kalinovskiy does not say who identified them. Consequently, the upper part of the section is tentatively referred to the Upper Jurassic on the basis of its conformable position on the Middle Jurassic beds containing Bothonian and Bajocian faunas as much as on the basis of Upper Jurassic index fossils.

A very similar section of marine Jurassic beds is given by Kalinovskiy (1952) for the northeastern part of the Ol'doy downwarp (basin of the Great Never River; for its correlation see Fig. 2). The entire Jurassic section and its separate parts is varied in facies along the strike. The percentage clastic sandy material and the grain size increase from northeast to southwest. This is especially clear in the middle part of the section.

Farther east along the Amur River, in the upper basin of its tributaries, the Osezhina and Burinda Rivers, on the northern margin of the large Amur downwarp, Jurassic marine sediments are also present and are represented by interbedded sandstone and gray argillite which pass upwards in the section into coarser-grained sandstone.

The exposures in this region do not allow the construction of an accurate section. Marine Early and Middle Jurassic faunas have been collected at different points in the region, as for example, in the basin of the Osezhina and Kerek Rivers, by Khlaponin in 1927, and in the Osezhina River basin, by Savrasov in 1934.

Apparently, the upper beds of the section containing mainly coarse-grained sandstone must be tentatively correlated with the Jurassic section of the Ol'doy downwarp and assigned to the Upper Jurassic. West of this large downwarp, marine Jurassic deposits are exposed in a band with a northeastern trend to form the Amazar downwarp. They lie transgressively and unconformably on the dislocated Middle Paleozoic and partly on fossiliferous Triassic deposits[1] in the Amazar River valley.

According to the data of B.G. Kuznetsov and A.D. Britchenko (1952), these deposits are represented here by a lithologically uniform sequence of bluish, dark-gray siltstone and silty shale interbedded with medium-grained, dense, polymict sandstone. In the upper part of the section the sandstone becomes dominant and the layers of silty shale almost disappear. At the base of the section lies a basal conglomerate composed of well-rounded pebbles of the underlying Paleozoic rocks (quartzite, metamorphosed sandstone and shale and basalt porphyry). The total thickness of the Jurassic deposits, according to these authors, is about 1800 m.

To the north, northwest and northeast, along the periphery of the region of distribution of Jurassic marine beds, at the foot of the Stanovoy and Yankan ranges and in the lower course of the Shilka River, there are small isolated areas of Jurassic near-shore and continental sediments consisting of conglomerate, polymict sandstone and siltstone. These sediments are highly varied in facies. The sediments contain numerous plant imprints.

In the valley of the Urkan River, Kirillov (1942) and N.F. Levykin (1953) collected Podozamites lanceolatus L. et H., Cladophlebis haiburnensis Sew., C. Tchihatchewii Heer, Ginkgo sibirica Heer and other plants.

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[1] Upper Triassic sediments were first recognized in the Amazar River valley in 1953 by Ye. A. Modzalevskaya.

In the lower course of the Shilka River in 1954, Ye. A. Modzalevskaya and M.N. Petrusevich found plant remains identified by I. Srebrodol'skaya as Cladophlebis sp., Coniopteris sp., Ginkgo schmidtiana Heer, Phoenicopsis angustofolia Heer, P. speciosa Heer, Pityophyllum longifolium Nath., Carpolithes cinctus Nath., C. dahuricus Pryn., Sphenopteris transbaikalica Pryn, etc.

In Srebrodol'skaya's opinion, this flora indicates a Jurassic and probably Middle Jurassic age.

These forms are found also in the Jurassic sediments containing marine fauna described above.

The general coarse-grained character of the sediments lying north of the periphery of the area of distribution of marine Jurassic beds and the rapid facies changes in them suggest that they are near-shore facies of marine Jurassic sediments, as described earlier. The flora which establishes their age equivalence with marine deposits confirms this supposition.

The zone of distribution of near-shore marine and continental Jurassic deposits at the foot of the Stanovoy and Yankan ranges fixes the northern limit of the Jurassic sea in this region. It is much more difficult to determine its southern limit because the adjacent regions of Northern Manchuria have been little studied.

No fossiliferous Jurassic marine sediments have thus far been found in the Amur-Zeya downwarp of the Zeya River basin. It is possible that the lithologically similar sandstone-shale deposits of the upper Amur region, which underlie the coal-bearing sequence (J -- Cr), should be referred to the Jurassic. These sediments are widespread farther east in the Bureya River basin.

The Jurassic marine sediments of the Bureya River valley, according to N.P. Kheraskov, T.N. Davydov and G.F. Krasheninnikova [10], are represented by all three stages of the Jurassic. The sandstone-shale deposits of the Umal'tinsk formation carrying Middle and Late Liassic fauna belong to the lower stage; the sandstone-shale beds belong to the middle stage; these beds contain infrequent thin layers of sandy limestone with Upper Aalenian, Bajocian and Bethonian fossils. They form the upper Umal'tinsk and Epikan formations and also the lower part of the El'ginsk formation. The upper part of the section of the El'ginsk formation, which contains numerous remains of Modiola ozekanowskii Lahus, M. solenoides Morr. and Lycett, Pseudomonotis umaltensis Krimh., and other forms, belongs, in G. Ya. Krymgol'ts' opinion [3], to the Upper Jurassic (Callovian).

To the west of the Upper Amur region, in Eastern Transbaikalia, the marine Jurassic is found over a relatively small territory in the East Transbaikalian downwarp in the basin of the right tributaries of the Onon, Turga and Borzya Rivers and in the region of the Gazimur mill. The Jurassic sea did not spread farther west into Central and Western Transbaikal, and the deposits of this period are represented there by coarse-grained continenental volcanic and sedimentary rocks. In Eastern Transbaikal, marine Jurassic sediments are interbedded sandstone and argillite with a thin bed of basal conglomerate.

Coarse-grained sandstone with conglomeratic layers is dominant in the upper part of the section of the marine Jurassic.

The total thickness of marine Jurassic deposits of Eastern Transbaikalia is about 4000 m.

On the basis of rather abundant paleontologic material collected in the 1930's by I.E. Khudyayev (1931) and others and of the numerous additional collections made in later years (by Ye. V. Pavlovskiy and I.V. Luchitskiy, V.N. Kozerenko, A.F. Mushikov and others), it is known that in Eastern Transbaikalia Jurassic marine sediments are represented by the lower and middle stages, beginning with the lower Lias and ending with the Bathonian. The deposits of the upper stage lie with sharp angular unconformity on the Lower and Middle Jurassic folded sandstone and shale cut by granitic intrusions, and are represented by a very different complex of coarse-grained sediments and volcanics accumulated under continental conditions.

Thus, at the beginning of the Upper Jurassic the sea finally left the region of Eastern Transbaikalia, but in the neighboring territories of the upper Amur region and in the Bureya River basin it persisted through the Late Jurassic. The Upper Jurassic deposits in the upper waters of the Amur River are mainly shallow water sediments, medium and coarse-grained sandstone with lenses of small-pebble conglomerate and infrequent layers of dark-gray argillite.

UPPER JURASSIC AND LOWER CRETACEOUS FRESHWATER-CONTINENTAL DEPOSITS

In the headwaters of the Amur River, there is a thick series of freshwater-continental coal-bearing sediments lying perfectly conformably on the Upper Jurassic

marine deposits. These sediments are mainly clastics, alternating beds of conglomerate, sandstone, siltstone, argillite and carbonaceous shale with layers of pyroclastics and, much less commonly, thin felsite flows among the lower beds.

The freshwater-continental deposits extend in a broad band along the left bank of the Amur River, forming the central part of the large Amur downwarp, which has a northeast, almost meridional, trend. These sediments are much less widespread in the basins of the Great Never and Ol'doy Rivers, where they occur in the southwestern, the most depressed, part of the Ol'doy downwarp (Fig. 1). These deposits of the upper Amur region have been little studied, although rather detailed stratigraphic sections based on lithologic characteristics and usually abounding in local formation names have been constructed by different authors for various areas within the region.

In the course of geologic reconnaisance the writer was able to study freshwater-continental sections over a long distance along the left bank of the Amur River and its left tributaries. As a result of these studies and on the basis of the data collected by previous investigators, the section of the freshwater-continental deposits in the upper Amur region (Amur downwarp) may be rather clearly subdivided into three parts on the basis of lithology.

1. The lower part of the section consists of an alternation of mainly arkosic sandstone with argillite and, locally, with siliceous volcanics. The author proposes to call this part of the section the Osezhina formation, because the volcanics which distinguish it from other Mesozoic freshwater-continental deposits of the upper Amur region are most widely distributed in the basin of the Osezhina River (a left tributary of the Amur). The thickness of the Osezhina formation is about 1000 m.

2. The middle part of the freshwater-continental deposit is coal-bearing, with layers of coal and carbonaceous shale distributed irregularly among sandstone and shale containing conglomeratic layers. They are concentrated mainly in the lower and upper parts of the section of the coal-bearing formation and are separated by barren graywacke with lenses of small-pebble conglomerate.

The author proposes that the coal-bearing formation as a whole be called the Tolbuzin formation, after the Tolbuzin coal deposit, the largest in the upper Amur region, which is present in this formation. Three subformations can be separated on lithologic grounds within the Tolbuzin formation: a) the lower Tolbuzin (coal-bearing) subformation (700 m), b) the middle Tolbuzin formation (barren) subformation (350 m) and c) the upper Tolbuzin (coal-bearing) subformation (300 m). The total thickness of the Tolbuzin formation is about 1350 m.

3. The upper part of the freshwater-continental deposits in the upper Amur region differs sharply from the two underlying formations composed of thick conglomerate and coarse-grained polymict sandstone beds. The author proposes that the upper part of the continental Mesozoic sequence be called the Peremykino formation, because the most complete section of this formation occurs in the excellent, craggy exposure on the left bank of the Amur below the village of Peremykino in the so-called Peremykino bend.

The Peremykino formation is subdivided (base to top) into: a) the lower Peremykino (conglomeratic) subformation, which is composed of large-pebble and boulder conglomerate with beds of coarse-grained sandstone in the upper part, and is 500 m thick; and b) the upper Peremykino subformation (sandstone) which is composed of coarse-grained sandstone with thin layers and lenses of small-pebble conglomerate and of thin beds of siltstone in the upper part. This subformation is 900 to 1000 m thick. The total thickness of the Peremykino formation is 1200 to 1500 m.

The three freshwater-continental formations are perfectly conformable with each other and have gradational contacts.

The correlation of stratigraphic sections of the continental deposits, constructed by various investigators of the upper Amur region, is given in Table 1.

The table shows that the lithologic-stratigraphic subdivisions defined by the author correlate rather well with the majority of the local stratigraphic sections of the freshwater-continental deposits constructed by different geologists for individual areas of the upper Amur region. The sharp variations in the reported thickness of some formations and subformations in different areas are to be explained by the incompleteness of the sections in some areas and the inexactness of measurements due to the complexity of dislocations in some localities and, in part, by the actual variations in the thickness of the deposits in different parts of the upper Amur region.

The correlation of sections from the vicinity of Beytnovo and Peremykino villages and from the vicinity of the village of Tolbuzino indicates that along the west-east

Table 1

Synonymy of the Continental Mesozoic Formations of the Upper Amur Region
(thicknesses are given for different regions)

<table>
<tr><th>P. F. Popov, 1932</th><th colspan="2">N.P. Savrasov, 1933</th><th>B.A. Ivanov, 1938</th><th>S.S. Dobrynin, 1941</th><th>V.D. Prinada, 1946</th><th>N.A. Brumel', 1948</th><th>A.I. Arkhangel'skiy, 1950</th><th colspan="2">M.S. Nagibina, 1954</th><th>Age according to M.S. Nagibina</th></tr>
<tr><td>Chelbuchinsk formation, 600 m</td><td colspan="2"></td><td rowspan="7">The section is not correlative with other known sections.</td><td>Chelbuchin formation, 650 m</td><td></td><td></td><td></td><td rowspan="3">Peremykino formation</td><td>Upper Peremykino subformation, 900-1000 m</td><td rowspan="3">Lower Cretaceous</td></tr>
<tr><td rowspan="2">Peremykino formation, 900 m</td><td rowspan="3">Talbuzino formation</td><td rowspan="2">Conglomerate-sandstone unit, 200 m</td><td rowspan="2">Conglomerate formation, 900 m</td><td rowspan="2">Conglomerate-sandstone formation, 400 m</td><td>Conglomerate formation, 350 m</td><td rowspan="2">Tolbuzino formation, 350 m</td><td rowspan="2">Lower Peremykino subformation, 500 m</td></tr>
<tr><td>Sandstone-conglomerate formation, 100 m</td></tr>
<tr><td rowspan="3">Beytonovo productive formation, 700 m</td><td>Productive unit, 200 m</td><td>Upper coal-bearing formation, 700-900 m</td><td rowspan="2">Freshwater deposit, 1100 m</td><td>Ul'dugichinsk formation, 250 m</td><td rowspan="2">Beytonovo-Peremykino productive formation, 1000 m</td><td rowspan="3">Tolbuzino formation</td><td rowspan="2">Upper Tolbuzino subformation, 300 m</td><td rowspan="4">Top of Upper Jurassic-Lower Cretaceous</td></tr>
<tr><td colspan="2" rowspan="2">Bol'shaya Ul'dugichinsk formation, 400 to 500 m</td><td>Sandstone-conglomerate formation, 450 m</td><td>Intermediate formation, 200 m</td></tr>
<tr><td>Lower coal-bearing formation, 350 m</td><td rowspan="2"></td><td>Butefsk formation, 400 m</td><td>Butefsk formation, 500 m</td><td>Middle Tolbuzino subformation, 350 m</td></tr>
<tr><td>Alabazino formation</td><td colspan="2">Lower arkose-shale formation, 500 m</td><td>Arkose formation</td><td></td><td></td><td colspan="2">Osezhino volcanic-sedimentary and sandstone-shale formation, 1000 m</td></tr>
</table>

trend of the Amur depression the thickness of a number of subformations of the Tolbuzin formation decreases by about one-third.

The general thickness of the freshwater-continental deposits of the Amur downwarp ranges from 3200 to 3900 m. To the west, in the Ol'doy downwarp, their thickness is 1200-1400 m.

These sediments are represented in the Ol'doy downwarp by a rather uniform mass of light-colored medium- and coarse-grained sandstone, cross-bedded siltstone and argillite (sandstone formation). The upper part of the freshwater-continental deposits is composed of sandstone with beds of conglomerate and thin lenses of carbonaceous shale (sandstone-conglomerate formation) and is 300 to 500 m in thickness. The upper sandstone-conglomerate formation corresponds in its stratigraphic position and lithology to the Peremykino formation.

The stratigraphic section of freshwater-continental deposits of the upper Amur region as given above does not agree with the section given by Skorokhod [9]. His two freshwater-continental formations separated by marine deposits do not exist in the upper course of the Amur River. Skorokhod's division of the deposits into lower and upper Nikansk formations separated by a middle marine Nikansk sequence was based, apparently, on an erroneous interpretation of the repetition of the freshwater-continental section in the outcrops on the left bank of the Amur River caused by the displacement of parts of the section along a large fault.

The assignment of ages to these formations is a very difficult problem. Below, the author attempts a very tentative approach to this problem, using the relatively scant data available at present. The lower age limit of these formations is set by the Upper Jurassic marine sediments of the Ol'doy and Amur downwarps.

Plant impressions have been collected from the Osezhina, Tolbuzino and Peremykino formations by different investigators, including the author. Below they are listed according to the formations.

Osezhino Formation

Sphenopteris sp., Coniopteris sp., C. concina Heer, Cladophlebis haiburnensis L. et H.,[1] Nilssonia acutiloba Heer, N. schmidtii (Heer) Seward, Phoenicopsis speciosa Heer, Ph. angustifolia Heer, Czekanowskia rigida Heer,[1] Cz. setacea Heer, Podozamites lanceolatus I. et H.

Tolbuzino Formation

Lower Tolbuzino subformation: Sphenopteris sp., Coniopteris burejensis (Zal.) Seward, Cladiphlebis haiburnensis L. et H.,[1] Cl. spectabilis Heer, Nilssonia schmidtii Heer, Pseudoctenis sp., Ginkgo sibirica Heer, Czekanowskia rigida Heer,[1] Podozamites lanceolatus L. et H.

Upper Tolbuzino subformation: Coniopteris concina Heer, Cladophlebis spectabilis (Heer) Fontain, Ginkgo sibirica Heer, Phoenicopsis speciosa Heer, Ph. angustifolia Heer, Czekanowskia rigida Heer.

Peremykino Formation

Equisetites burejensis Heer, Coniopteris burejensis (Zal.) Seward, Cladophlebis denticulata (Brong.) Fontain, Nilssonia jorekensis Pryn.,[1] N. aff. orientalis, Podozamited lanceolatus L. et H.,[1] P. latifolius Heer.[1]

The Zeya-Dep region. East of the upper Amur region freshwater-continental deposits are traceable in a continuous band in the valleys of the Zeya and Dep Rivers. Near the village of Chernyayevo (on the Amur) the band abruptly changes its northwest, nearly east-west trend and strikes northeast. The freshwater-continental deposits are localized in the large Amur-Zeya downwarp, which trends northeast and is a direct continuation of the northwest trending Amur downwarp.

Within the Amur-Zeya downwarp the freshwater-continental deposits form a continuous band extending for 200-250 km from the Amur River into the middle reaches of the Zeya River and into the valley of the Dep River, forming a single Amur-Zeya coal-bearing basin. Northeast of the village of Chernyaevo, the coal-bearing sediments are partly covered by unconsolidated Upper Cretaceous and Tertiary deposits. In this region the facies composition of the freshwater-continental deposits is different from that in the upper course of the Amur. Volcanic rocks begin to dominate. Through almost the entire section they are repre-

[1] Plants collected by the author and determined by V. A. Vakhrameyev.

sented by siliceous light-colored tuff, sandy tuff and tuffaceous sandstone, forming thin layers among the sedimentary rocks. In the upper Amur region tuffs of the same composition and thin felsitic flows occur only in the lower parts of the Osezhino formation.

In the region of the Zeya and Dep Rivers, the coal content of the sediments increases sharply and beds of coal and carbonaceous shale of different thickness are distributed throughout the section. In the upper Amur area, only the middle part of the section, the Tolbuzino formation, contains coal.

In the upper part of the section, in the region of the Zeya and Dep Rivers, the amount of coarse-grained material decreases notably compared with the sections of the upper Amur area; the conglomerate occurs only in thin layers and lenses among sandstone, siltstone and carbonaceous shale.

Investigations of the freshwater-continental deposits of the middle course of the Zeya and Dep Rivers have been conducted by many geologists, beginning in 1912 (S. F. Malyavkin). In recent years the deposits have been studied by V. V. Onikhimovskiy, A. I. Arkhangel'skiy, D. M. Sayapina, R. M. Tonoyan, Ye. Ye. Krasnyanskaya, N. Ye. Slastenova, the present author and others. In spite of this, poor exposures, uniformity of composition, and scarcity of fossils make it very difficult to determine the stratigraphy of these deposits.

Below is the stratigraphic section of this region, based on the latest data of Sayapina and Tonoyan (1952-1953), who did geologic mapping and reconnaisance work in the basin of the Dep River and in the middle course of the Zeya River, and on additional studies by Ye. Ye. Krasnyanskaya and the author (base to top):[1]

1. The Ayak coal-bearing formation is composed of interbedded gray arkosic and polymict, less commonly tuffaceous, sandstone. Interbedded with the sandstone are layers of argillite, and in the upper part of the formation, beds of carbonaceous shale and coal. The thickness of the Ayak formation is 1000 m.

2. The Dep coal-bearing formation consists of interbedded polymict sandstone, siltstone, argillite containing coal beds, siliceous tuff and sandy tuff, conglomerate and occasional thin beds of brown sandy limestone. At the base of the formation lies a bed of conglomerate. The thickness of the Dep formation is 2300 m.

3. The Molchansk coal-bearing formation is composed mainly of medium- to coarse-grained gray and yellowish-gray sandstone. The sandstones are polymict, arkosic, tuffaceous and have argillaceous or, less commonly, calcareous cement. Among the sandstone there are layers of argillite, siliceous tuff, coal, carbonaceous shale and conglomerate.

At the base of the formation lies a bed of conglomerate. The thickness of the formation is about 1000 m.

All three formations are conformable.

The Verkhnemolchansk formation defined by Krasnyanskaya during the investigations of 1951-1954 in the basin of the Dep River lies on the slightly eroded surface of the Molchansk coal-bearing formation.

The lower part of the Verkhnemolchansk formation consists of cobble and boulder conglomerate (the cobbles are from 20 to 40 cm in diameter) containing 70 to 80 percent sandstone-shale cobbles derived from the underlying formation and 20 to 30 percent pebbles derived from metamorphosed igneous rocks. The cobbles are cemented by polymict sandy material. The middle and upper parts of the Verkhnemolchansk formation consists mainly of fine-grained, mainly tuffaceous sandstone which includes thin beds of coal very high in ash. The thickness of the formation is about 800 m.

The upper age limit of the formation, according to Krasnyanskaya (1954), is set by the Upper Cretaceous volcanics.

The total thickness of the freshwater-continental deposits in the Amur-Zeya downwarp is about 5000 m.

The basal beds of the Ayak formation, according to M. S. Nagibina (1948), on the left bank of the Zeya River below the mouth of the Dep, lie on the eroded surface of Paleozoic granulated, serpentinized gabbro and contain pebbles of this rock. To the northwest, above the mouth of the Ulunga River in a number of places, sandstone and

[1] Following Arkhangel'skiy, Sayapina and Tonoyan recognized the so-called Zeya formation at the base of the freshwater-continental deposits of the Zeya-Dep region and correlated it with the Zeya formation of G. Ye. Bykov [1] who included under this name the entire section of thick Mesozoic deposits in the vicinity of the village of Inaragda (upper Zeya depression), equivalent in age to the entire freshwater-continental deposits of the Zeya-Dep region. In my opinion, the section should begin with the Ayak formation, whose basal beds lie on the eroded surface of Paleozoic bedrock.

shale containing sparse, poorly preserved plant remains are exposed beneath the coal-bearing strata. It is possible that they also are analogues of the lower beds of the Ayak formation or belong to deposits similar to the marine Jurassic sediments of the Upper Amur region.

No fossils confirming this hypothesis have thus far been found.

Below is a list of fossils from this section compiled from the data of Nagibina, Arkhangel'skiy, Myachina, Slastenova Begunkov and others.[1]

The Ayak Formation

Equisetites sp., Podozamites lanceolatus L. et H., Pitophyllum nordenskioldii (Heer) Nath. Near the village of Chernyayevo on the Amur River, Slastenova (1955) collected a freshwater fauna from the Ayak beds containing, according to G.G. Martinson, Bithyna cf. andraeae (Ramm), Plicatounio lacustris nov. sp., Hydrobia cf. zeica nov. sp., H. gracilis nov. sp., Valvata cf. turgensis Martins, Cyrena fragilis nov. sp., Unio cf. pseudomargaritana Martins, etc.

The Dep Formation

Coniopteris burejensis (Zal.) Sew.,[2] Cladophlebis denticulata (Brong.) Font.,[2] C. argutula (Heer) Font.,[2] Phoenicopsis speciosa Heer.[2]

In 1954, A.I. Myachina (Far Eastern Geologic Administration) collected and studied rich spore and pollen material from the Dep and the overlying Molchansk and Verkhnemolchansk formations.

The spores and pollen from the Dep formation determined by Myachina are listed in Fig. 3.

In the Dep formation, according to Myachina, the pollen of gymnosperms amounts to 53.4 to 86.0 percent.

In the Molchansk formation, Myachina (1955) found a) the gymnosperm pollen of Ginkgo gibbirosa Naum., G. subminor Naum., G. Typica (Mol.); and b) spores of the following ferns: Gleichenia stellata Bolch., G. lacta Bolch., Trachytriletes ancoraeformis Bolch., T. crassus Naum., Osmunda sp., etc.

Unlike the Dep formation, the Molchansk formation contains abundant fern spores, which constitute 55.4 to 85.3 percent of the total spore and pollen content. The genera Gleichenia (23.5 to 65.3 percent) and Osmunda (15.7 to 65 percent) predominate in the assemblage.

In the Verkhnemolchansk formation, Myachina (1955) found spores and pollen in only one sample, but she believes that the spore and pollen assemblage of this formation differs sharply from that of the Molchansk formation. In the Verkhnemolchansk formation the pollen of the gymnosperm Pinaceae amounts to 91 percent, while spores constitute only 6.4 percent and angiosperm pollen, 3.4 percent (Lower Cretaceous forms) of the total.

Southwest of the Zeya River valley the freshwater-continental deposits are buried under unconsolidated Tertiary sediments and are exposed only locally in deep valleys of the right tributaries of the Zeya River (Tygda, Sivak and others). These deposits were studied by I.T. Bebunkov (1954-1955) in a series of holes drilled according to his direction in the middle valley of the Tygda River and in the upper course of the Sivak River as well as in a number of outcrops.

According to Begunkov (Far Eastern Geologic Administration), Mesozoic deposits were reached by the drillholes under the unconsolidated Tertiary sediments at depths ranging from 3.8 to 115.1 m. The maximum depth of the drillholes was 390 m. The deposits penetrated by the holes are fine-grained to coarse-grained sandstone, less commonly dark-gray siltstone and argillite interbedded with tuffaceous sandstone containing layers of small-pebble conglomerate ranging from 0.2 to 31.35 m in thickness.

The sandstones are polymict, arkosic and, less commonly, tuffaceous, thinly laminated and cross-bedded rocks. In a number of drillholes (1, 2, 6a) at different depths a freshwater fauna are found and determined by Martinson and M.I. Mandel'shtam.

From drillhole #2, Martinson determined Mycromelania hydrobiodes nov. sp., which in his opinion indicates a lower Cretaceous age.

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[1] The flora lists of the older works are not included because the exact localities for individual fossils are unknown. It is impossible, therefore, to assign them to a particular formation.

[2] Identified by V.A. Vakhrameyev in the author's collections.

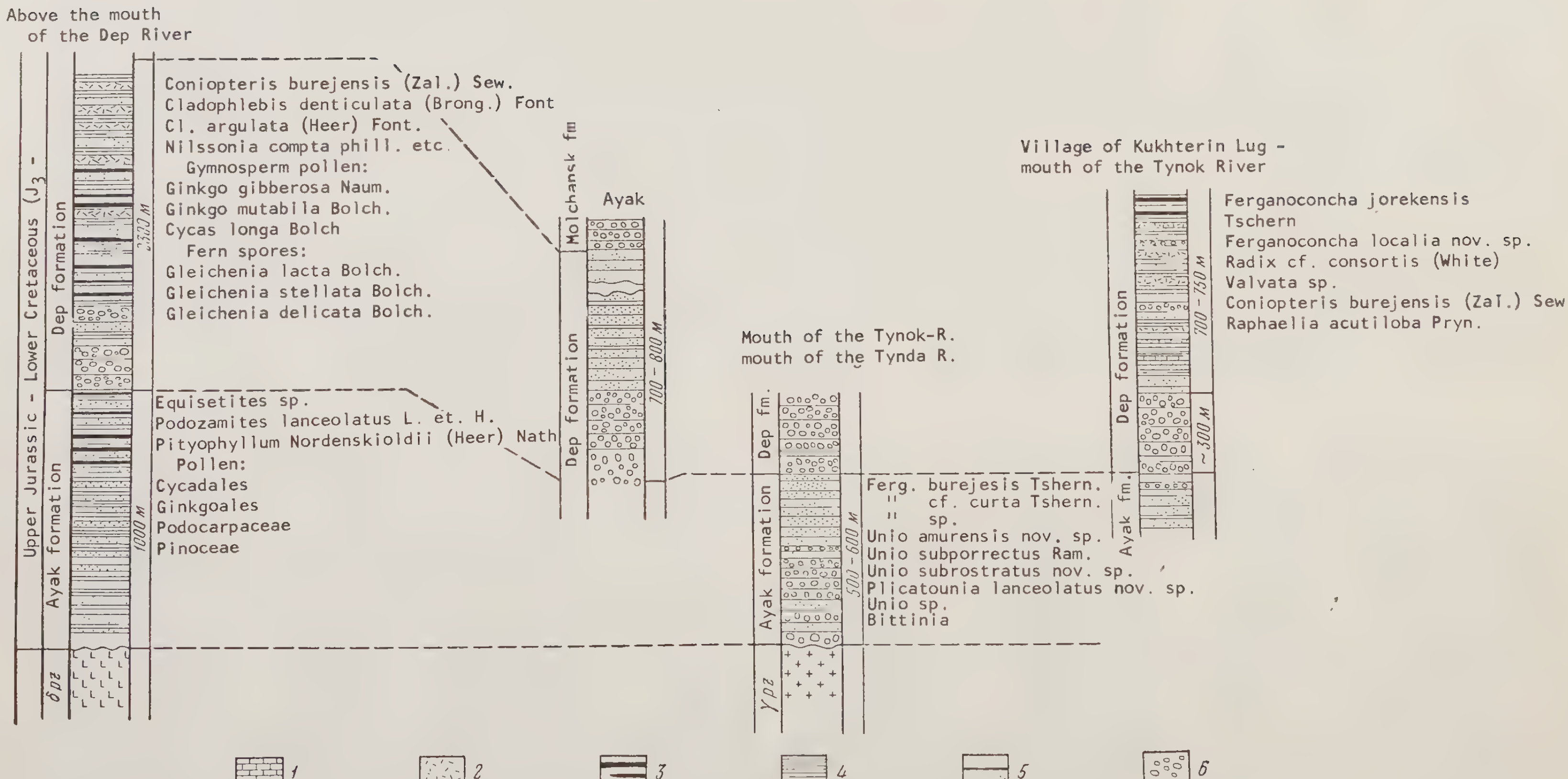

Fig. 3. Correlation of sections of freshwater-continental deposits of the middle course of the Zeya River

1 -- sandy limestone, 2 -- acid tuff and sandy tuff, 3 -- carbonaceous shale and coal, 4 -- argillite and siltstone, 5 -- sandstone, 6 - conglomerate

From the fossil faunas of drillholes #1 and #6a, Mandel'shtam described a new genus -- Zejaina -- and two species belonging to it, Zehaina exsortis Mandel'shtam sp. n. and Z. spritata Mandel'shtam sp. n.[1] The form of the shells is near that of the genus Mongolionella Mandel'shtam (1956).

Mandel'shtam believes that this fauna is probably of Lower Cretaceous age.

Lithologically, the sediments penetrated by the drillholes are very similar to the Verkhnemolchansk formation, which forms the upper part of the freshwater-continental deposits of the Zeya-Dep region, and according to the spores and pollen contained in it, is also Lower Cretaceous.

Farther southeast in the middle course of the Zeya River, below the village of Ayak, only the lower parts of the freshwater-continental deposit are exposed. The thickness of the deposit is much diminished here. On the right bank of the Zeya River, above the Bezrodnyy Spring, it lies on the eroded surface of Paleozoic biotite-hornblende granite. Its basal unit is a coarse conglomerate containing boulders of different rocks ranging from 30 to 40 cm in diameter, cemented with coarse arenaceous material. Among the boulders are rounded blocks of biotite-hornblende granite 50 cm in length. The conglomerate contains numerous lenses of coarse-grained polymict sandstone. The thickness of the basal conglomerate is 200 to 250 m. Higher in the section the conglomerate is gradually replaced by light-gray coarse-grained, cross-bedded sandstone containing lenses of small-pebble conglomerate with infrequent thin layers of greenish-gray fine-grained sandstone and siltstone, 1 to 1.5 m in thickness, locally containing ferruginous concretions up to 20 cm in diameter. In the upper part of the section the sandstone becomes medium-grained and contains thin layers and lenses of argillite and carbonaceous shale. The total thickness of the sandstone and conglomerate formation, which according to their stratigraphic position are analogues of the Ayak formation, is about 500 to 600 m in this locality.

In the lower course of the Tygda River and in the Zeya River valley below the mouth of the Tygda, in the sandstone and and argillite of this formation, Begunkov and Slastenova found a freshwater fauna, which was determined by Martinson (see Fig. 3).

[1] Descriptions of the new genus and the two new species have been sent by Mandelshtam to the press.

Stratigraphically above the light-gray sandstone and resting conformably upon them, lies a thick (about 1000 m) formation containing a conglomeratic unit at the base (up to 300 m thick) composed of pebbles, cobbles and boulders. The cobbles are up to 30 to 50 cm in diameter. The fragments are granite, black siliceous shale, red and green metamorphosed siltstone and andesite cemented by coarse-grained sand and small pebbles. The conglomerates are stratified and contain layers and lenses of coarse-grained sandstone. Higher in the section the conglomerates are succeeded by sandstone interbedded with siltstone and argillite, tuff, and, less commonly, brownish-red sandy limestone and lenses of small-pebble conglomerate. The thickness of individual layers is 0.2 to 0.6 m. The sandstone and siltstone commonly have calcareous cement. In the upper part of the section the number of argillite layers, tuff and tuffaceous sandstone increases and thin layers and lenses of carbonaceous shale appear.

In the upper part of the section, Begunkov and Slastenova (1954-1955) found a freshwater fossil fauna in which Martinson identified Ferganoconcha jorekensis Tschern., F. localica nov. sp., Radix cf. consortis (White) and Valvata sp.

This sequence is a stratigraphic analogue of the Dep formation, which it very closely resembles lithologically. It is possible that its uppermost beds should be correlated with the Molchansk formation.

The species Ferganoconcha jorekensis Tshern. was first described by B.I. Chernyshev (1938) from the upper part of the freshwater-continental deposit of the Bureya basin (Chemchukin formation) occurring along the Malyy Iorek River.

On the right bank of the Zeya River, above the mouth of the Malyy Ayak River, stratigraphically above the sandstone and argillite of the Dep formation, lie cobble conglomerates with arenaceous cement composed mainly of sandstone and argillite pebbles derived from the underlying rocks. In the opinion of Krasnyanskaya and the author, it is possible that these conglomerates are analogues of either the Verkhnemolchansk or the Molchansk formation (see Fig. 3).

Farther east, freshwater-continental deposits are found in the Bureya basin, where they form the large Bureya and Tyrmin downwarps of northeast, almost north-south trend. The deposit has been studied in detail by Kheraskov, Davydov, Krasheninnikov and D.D. Penninskiy [10].

According to these investigators, the coal-bearing deposits of the Bureya basin lie conformably on the Upper Jurassic marine sandstone and shale sediments of the El'ginsk formation. On the basis of paleobotanic and lithologic data, these investigators divide the deposit into five formations (base to top): Talyndzhan, Urgal', Chagdamyn, Chemchukin, and Iorek, of which the upper two are nonproductive. The Chagdamyn and Urgal' formations have eastern productive and western nonproductive facies. Only the eastern facies of the Talyndzha formation is productive.

The general lithologic composition of the freshwater-continental deposits of the Bureya basin is very similar to that of the analogous deposits of the upper Amur and Zeya-Dep regions. The volcanics interbedded with sandstone, argillite and coal beds are represented in the Bureya basin by similar light-colored siliceous tuff and tuffaceous sandstone; but in contradistinction to the Zeya-Dep region, they are limited, as in the upper Amur region, to only the lower parts of the section of the freshwater-continental deposits -- the Talyndzhan formation.

The total thickness of these deposits in the Bureya basin is about 2000 m.

The deposits described from the vast territory of the upper Amur basin, both in the upper Amur region and in the Zeya-Dep and Bureya basins, exhibit rapid facies changes. This is due mainly to their accumulation in large intermont downwarps.

The general lithologic character and the very close similarity of fossil floras contained in the freshwater-continental deposits of these three regions, as well as their stratigraphic position (conformable attitude on the Upper Jurassic marine sediments), indicate their contemporaneity. It is difficult to make detailed age subdivisions, although some of the material collected up to date makes it possible to make very tentative correlations of some of the formations on basis of lithology and paleobotany.

The results of this correlation are given in the appended correlation chart (Table 2). According to Kheraskov and others [10], the upper formations of the Bureya basin contain the following plant remains (base to top):

a) In the Chemchukin formation: Coniopteris orientalis (Heer), Lycopodites burejensis sp. nov., Pterophyllum sensinovianum Heer, Ginkgo intergruiscula Heer, Sphenobaiera czekanowskiana (Heer), Nilssonia jorekensis Pryn. and others. Besides this there is a freshwater fauna with Ferganoconcha jorekensis Tshern., etc.

b) In the Chagdamun formation: Coniopteris gracilis (Heer), Nilssonia sinensis Jabe et Oishi, Taeniopteris amurensis Novop., etc. The floras of these two formations, in Vakhrameyeva's opinion, are characteristic of the Lower Cretaceous deposits of Eastern Siberia.

The species Taeniopteris amurensis Novop., according to Vakhrameyeva [1], is found in the Lena-Aldan region, mainly in the Lower Cretaceous formations lying directly on the beds containing marine fauna of the lower Volgian stage. Ginkgo intergruiscula (Ginkgo adianteides Ung.) is known only from the Lower Cretaceous. Unlike the Jurassic ginkgoes characterized by strongly lobate leaves, it has weakly lobate leaves.

On this evidence, the upper part of the freshwater-continental section of the Bureya basin must be referred to the Lower Cretaceous. The spore and pollen assemblage from these formations studied by Myachina (1943) also indicates their Lower Cretaceous age (Gleichenia, Lygodium, Anemia).

The Molchansk and Verkhnemolchansk formations of the Zeya-Dep region must also be assigned to the Lower Cretaceous on the basis of Myachina's studies of the spore and pollen assemblages.

In the upper Amur region, within the Amur downwarp, the upper part of the freshwater-continental deposits of the Peremykin formation contains Nilssonia jorikensis Pryn., widely distributed in the Lower Cretaceous Chemchukin formation of the Bureya basin.

Therefore, the Peremykin formation of the Amur downwarp can also be referred to the Lower Cretaceous. This formation, consisting of coarse-grained rocks (conglomerate, fanglomerate and coarse-grained sandstone), differs sharply from the underlying coal-bearing Tolbuzino formation and is easily mapped.

Farther west in Eastern Transbaikal, the Turinsk formation, lying with sharp angular unconformity on the upper Jurassic volcanic and sedimentary rock, contains a typical fossil flora and freshwater fauna and is referred to the Lower Cretaceous.

In the upper Amur region, the lower part of the freshwater-continental lies conformably beneath the Lower Cretaceous Peremykin formation; and in the Bureya basin, beneath the Chagdamyn formation, containing imprints of Taeniopteris amurensis Novop.

Table 2

Correlation Chart of Jurassic and Cretaceous Deposits of the Upper Amur Region and Adjacent Areas

<table>
<tr><th></th><th></th><th>Eastern Transbaikal
(composite section)</th><th></th><th>Ol'do downwarp
(after M. S. Nagibina)</th></tr>
<tr><td rowspan="3">Cretaceous</td><td>Upper Cretaceous-Tertiary</td><td>Andesite, basalt and liparite flows</td><td></td><td>Volcanic formation</td></tr>
<tr><td rowspan="2">Lower Cretaceous</td><td rowspan="2">Turginsk formation:
Lycoptera middendorfii I. Muller.,
L. macrorhyncha (Eichwald),
L. davidi (Sauvage),
L. ferox Grabau, etc.
Pollen: Platysaccus Naum.,
Trachitriletes globiformis Naum.,
Leiotriletes microrugosus (Gbr). Naum., etc.
Thickness 200 - 600 m</td><td>Lower Cretaceous</td><td>Analogue of the Peremykino formation (sandstone-conglomerate sequence)
Thickness 300-380 m</td></tr>
<tr><td rowspan="2">Upper Jurassic - Lower Cretaceous</td><td rowspan="2">Analogue of the Tolbuzino and Osezhino formations:
Czekanowskia rigida Heer,
Cladophlebis haiburnensis L. et H.,
Cl. sp., etc.
Thickness 1050 m</td></tr>
<tr><td rowspan="4">Jurassic</td><td rowspan="2">Upper Jurassic</td><td rowspan="2">Volcanic-sedimentary formation:
Phoenicopsis angustifolia Heer.,
Czekanowskia rigida Heer,
Cz. setacea Heer,
Cladophlebis haiburnensis (L. et H.)
Desmophyllum sp, etc.
Thickness 1500 m</td></tr>
<tr><td>Upper Jurassic</td><td>Sandstone
Aucella fischeri Dorf.,
Gryphaea aff. dillatato Sone
Modiola sp., Nucula sp.,
Pecten sp. Lima sp.,
Leda sp. Parallelodon sp.,
Tapes sp., Avicula sp.
Thickness 1500 m</td></tr>
<tr><td>Middle Jurassic</td><td>Formation of alternating sandstone and shale:
Garantia bifurcata (Liet.),
Pseudomonotis echinata Smith.var.,
Ps. elegans Goldf.,
Quenstedtia (Myacites) cf. sinistria Ag.,
Cyprina cf. loeweana Morr.et Lyc.
Myacites cf. ferratus Quenst, etc.
Thickness 2200 m</td><td>Middle Jurassic</td><td>Sandstone
Pseudomonotis echinata Smith.,
P. aff. elegans Goldf.
Greslia peregrina Phyll.,
Myacites sp.,
Inoceramus porrectus Eichw.,
In. lucyfer Lah.,
In. ambigus Ech.,
In. ussuriensis Voronetz.,
Limopsis sp., etc.
Limopsis sp., etc.
Thickness 2000 m</td></tr>
<tr><td>Lower Jurassic</td><td>Shale-sandstone formation
Pseudolioceras compactile (Simps.),
Porpoceras andraei (Simps.),
Dactylioceras cf. braunianum d'Orb.,
D. mucronatum d'Orb.,
Aegoceras centaurum d'Orb.,
Uptonia cf. jamesoni Sow., etc.
Thickness 1000 m</td><td>Lower Jurassic</td><td>Massive sandstone and conglomerate:
Crenatula olivex Quenst.,
Astarta sp., Cardita sp.,
Parallelodon sp.,
Leda sp., etc.
Thickness 300 m</td></tr>
<tr><td></td><td></td><td>Triassic, Paleozoic and older rocks</td><td></td><td>Triassic, Paleozoic and older rocks</td></tr>
</table>

Table 2 (Cont'd)

Correlation Chart of Jurassic and Cretaceous Deposits of the Upper Amur Region and Adjacent Areas

<table>
<tr><th colspan="2">Amur downwarp (Upper Amur region, after M.S. Nagibina)</th><th>Amur downwarp (Zeya-Dep region, after D.M. Sayapina, R.M. Tonoyan, Ye.Ye. Krasnoyanskaya, N.E. Slastenova and M.S. Nagibina)</th></tr>
<tr><td colspan="2">Volcanic formation</td><td>Volcanic formation</td></tr>
<tr><td colspan="2" rowspan="2">Peremykino formation

Equisetites burejensis Heer,
Coniopteris burejensis (Zal.) Seward.,
Cladophlebis denticulata (Brong.) Font.,
Nilssonia jorekensis Pryn.
N. muna orientalis,
Podozamites lanceolatus L. et H., etc.

Thickness 1500 m</td><td>Upper Molchansk formation:
Micromelania hydrobioides nov. sp.,
Zejaina exsortis Mandelstam sp. n.,
Z. spritata Mandelstam sp. n.
Thickness 800 m</td></tr>
<tr><td>Lower Molchansk formation

Gymnosperm pollen:
Ginkgo sumbinor Naum.,
G. typica (Mal.), etc.

Fern spores:

Gleichenia stellata Bolch.,
Trachytriletes ancoraeformis Bolch.,
T. crassus Naum.,
Osmunca sp., etc.

Thickness 1000 m</td></tr>
<tr><td rowspan="3">Tolbuzino formation</td><td>Upper Tolbuzino subformation
Coniopteris concinna Heer,
Cladophlebis spectabilis (Heer) Font,
Ginkgo sibirica Heer, etc.
Thickness 300 m</td><td rowspan="3">Dep formation:

Coniopteris burejensis (Zal.) Sew.,
Cladophlebis denticulata (Brong.) Font., etc.

Gymnosperm pollen:
Ginkgo gibberosa Naum.,
G. parva Naum., Cycas longa Bolch.

Fern spores:
Gleichenia laeta Bolch.,
Gl. stellata Bolch.,
Gl. delicata Bolch.

Thickness 2300 m</td></tr>
<tr><td>Middle Tolbuzino formation

Thickness 350 m</td></tr>
<tr><td>Lower Tolbuzino formation
Coniopteris burejensis (Zal) Sew.,
Nilssonia schmidtii Heer,
Czekanowskia rigida Heer, etc.
Thickness 700 m</td></tr>
<tr><td colspan="2">Osezhina formation:

Coniopteris concinna Heer,
Nilssonia acutiloba Heer,
Phoenicopsis angustifolia Heer,
Czekanowskia setacea Heer, etc.

Thickness 1000 m</td><td>Ayak formation
Podozamites lanceolatus L. et H., etc.
Bithynia cf. andracae (Ramm.)
Plicatounio lacustris nov. sp.,
Valvata cf. turgensis Martins.,
Cyrena fragilis nov. sp.,
C. carinata nov. sp.
Thickness 1000 m</td></tr>
<tr><td colspan="2">Interbedded sandstone and argillite: Lucina sp. (Lucina crassa Mar. et Lyc.), Tapes sp., Ostrea sp., etc.</td><td>Interbedded sandstone and argillite</td></tr>
<tr><td colspan="2"></td><td></td></tr>
</table>

Table 2 (Cont'd)

Correlation Chart of Jurassic and Cretaceous Deposits of the Upper Amur Region and Adjacent Areas

Region of the middle course of the Zeya River below the village of Ayak, after M. S. Nagibina	Bureya downwarp, after N. P. Kheraskov, T. N. Davydova, G. F. Krasheninnikov and more recent data	Upper Creta-ceous	
	Volcanic formation	Lower Cretaceous	Cretaceous
	Iorek formation Thickness 300 m		
	Chemchukin formation: Coniopteris orientalis (Heer), Lycopodites burejensis Pryn., Pterophyllum sensinovianum Heer, Ginkgo integriuscula Heer, Sphenobaiera czekanowskiana (Heer), Nilssonia jorekensis Pryn., Ferganoconcha jorekensis Tshern., F. burejensis Tshern, etc. Thickness 800-900 m		
	Chagdamyn formation: Coniopteris gracilis (Heer), Nilssonia sinensis Jabe et Oishi, Taeniopteris amurensis Novop. Thickness 300 m		
Dep formation: Ferganoconcha jorekensis Tshern., F. localica nov. sp., Radix cf. consortis (White), Valvata sp. Thickness 1000 m	Urgal'sk formation: Hausmannia magnifolia sp. nov., Chadophlebis haiburnensis (L. et H.), Nilssonia Schmidtii (Heer), Baiera gracilis Bunb., etc. Thickness 500 m	Upper Jurassic-Lower Cretaceous	
Ayak formation: Ferganoconcha burejensis Tschern F. cf. curta Tschern. Unio amurensis nov. sp., Un. subporrectus Ramm., Plicatounio lanceolatus sp. Thickness 500 - 600 m	Talyndzhan formation: Coniopteris burejensis (Zal.) Equisetites burejensis Heer, Nilssonia Schmidtii (Heer), etc. Thickness 400 m		
Paleozoic granitoids and basic rocks	Chagony formation Thickness 600 m	Upper Jurassic	Jurassic
	El'ginsk formation Modiola czekanowskii Lahm, M. Solenoides Morr. et Lycett., M. burejensis Voronetz., Pseudomonotis umaltensis Krimh., etc. Sphaeroceras era Krimh., Artocephalites orientalis Krimh., Camptonectes lens (Sow), Pholodomya polymorpha d'Orb., Pleuromya varians Agassiz, etc. Thickness 1800 m		
	Epikansk formation Thickness 1000 m	Lower Jurassic-Middle Jurassic	
	Upper Umal'tinsk formation Pseudolioceras beyrichi (Schloenb.), Ps. elegans (Quenst.). Mesoteuthis quenstedti (Opp.), Inoceramus ambiguus Eicnw. Thickness 550 m		
	Lower Umal'tinsk formation Amaltheus margaritatus Mansf., Pseudolioceras lythense (I. et B.), Mesotenthis cf. triscissa (Ian.), Oxytoma dumortieri Rollier. Oxynoticeras burcensis Voronetz, etc. Mytiloides dubius (Sow.) Thickness 600 m		
	Paleozoic and older rocks		

UPPER AMUR REGION

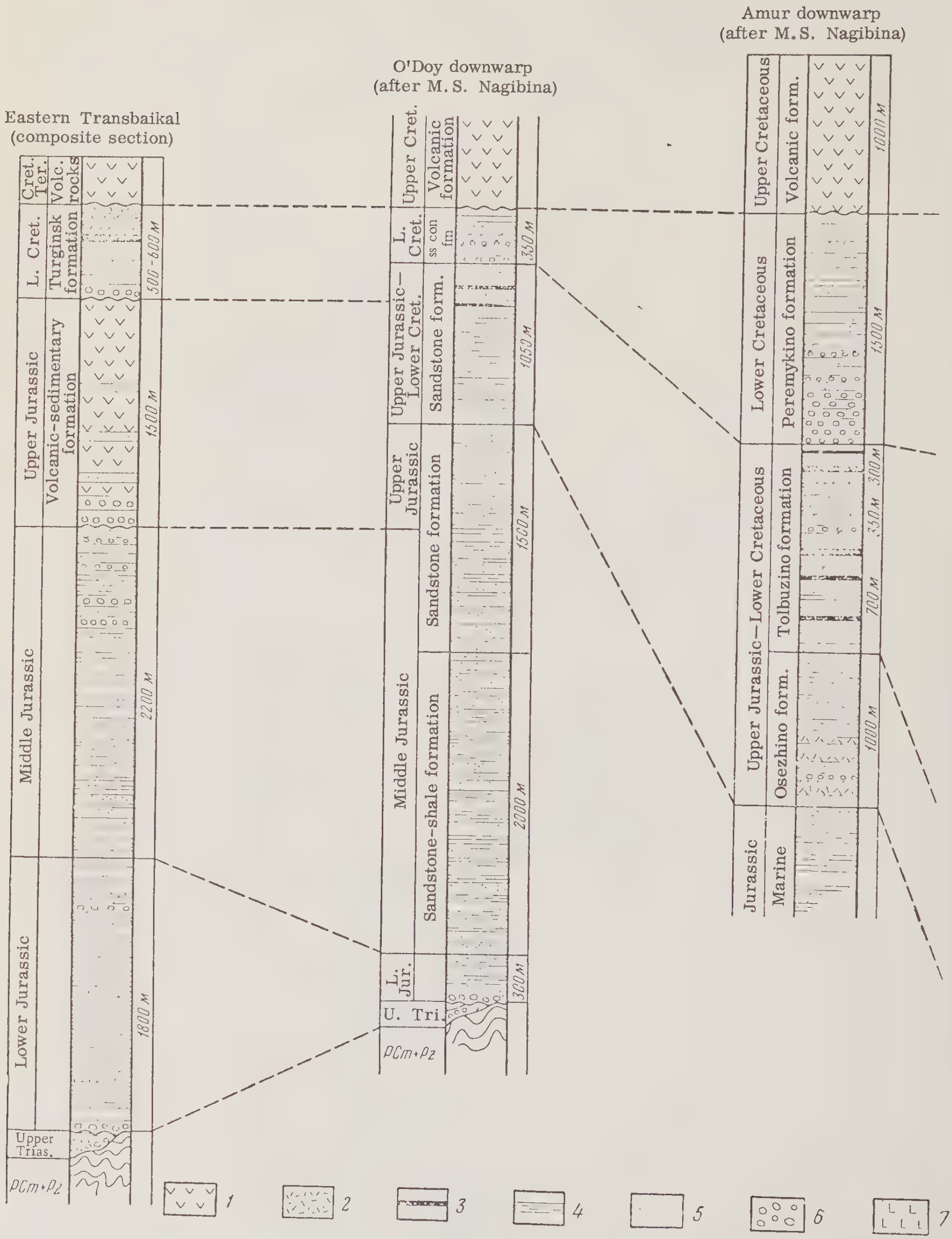

Fig. 4. Correlation of Jurassic and Cretaceous formations of the Upper Amur region and adjacent areas

1 -- Volcanics of different composition; 2 -- acid tuff and sandy tuff; 3 -- carbonaceous shale and coal; 4 -- argillite, 5 -- sandstone and siltstone, 6 -- conglomerate; 7 -- serpentized gabbro (Paleozoic)

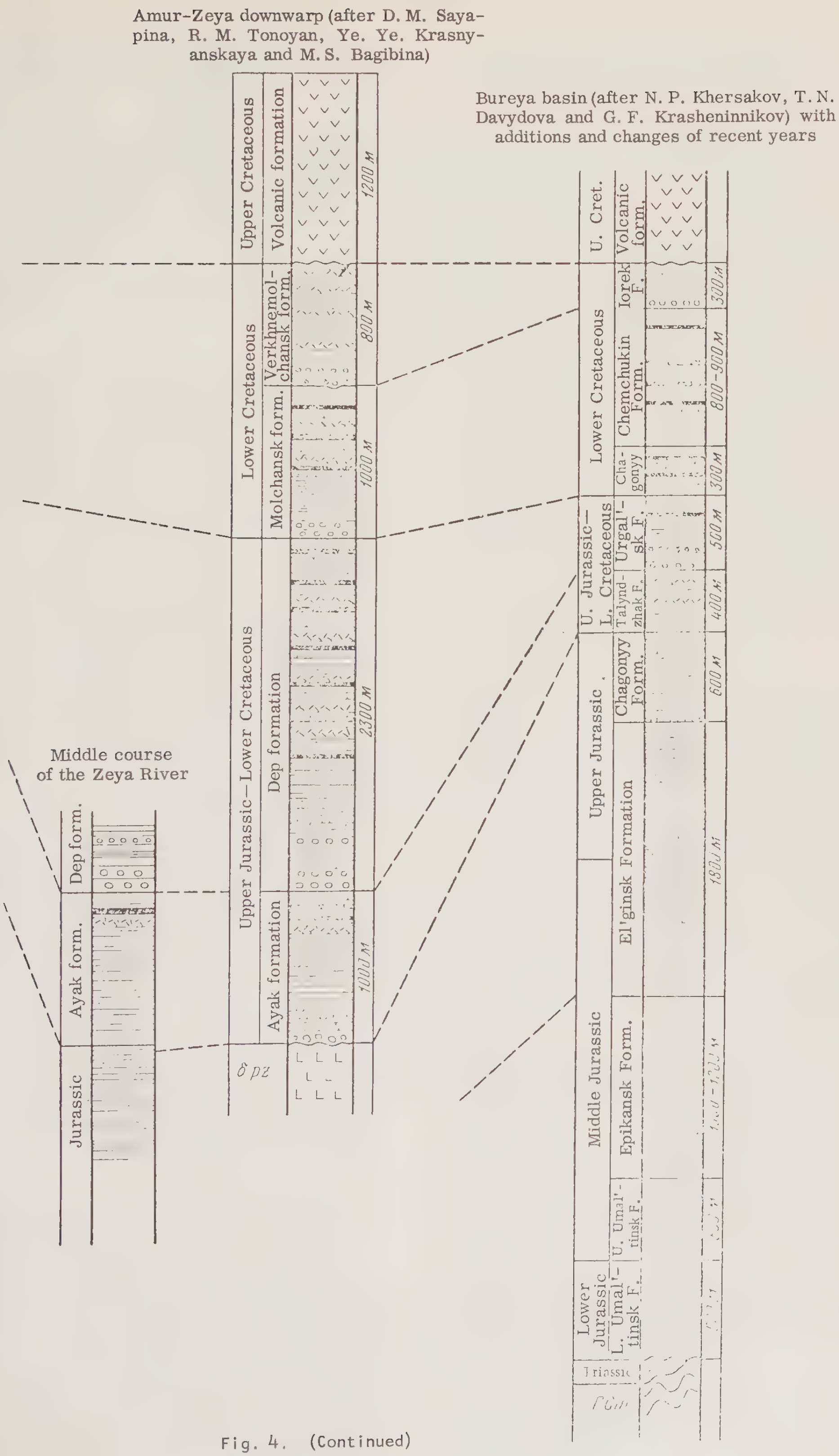

Fig. 4. (Continued)

These sediments, lying conformably on the fossiliferous Upper Jurassic marine rocks belonging to the Callovian stage, must be referred to the top of the Upper Jurassic and the base of the Lower Cretaceous. Their flora, in Vakhromeyeva's opinion, is transitional between the Upper Jurassic and Lower Cretaceous.

The freshwater fauna in the Ayak formation near the village of Chernyayevo on the Amur River, containing Bithynia cf. andracae (Ramm.), is similar, according to Martinson, to the fauna from the Ugangin (J - Cr) formation of Transbaikal and the Tsagandab (J - Cr) formation of Mongolia. The genus Plicatounio is a typical fossil of the uppermost Jurassic, Valanginian stage.

Thus, the Tolbuzin and Osezhino formations of the upper Amur River, the Ayak and Dep formations of the Zeya-Dep region and the Urgal'sk, Talyndzhyn and Chagdamyn formations of the Bureya River basin must be considered as Upper Jurassic and Lower Cretaceous (Fig. 4).

Summary

It is clear from the material presented here that the stratigraphic classification of the marine Jurassic strata in the upper Amur region is based, for lack of new fossil collections, on the old paleontologic material of Skorokhod, and has been only slightly refined by later investigators.

However, the stratigraphy of the freshwater-continental deposits of the upper Amur region was compiled by the author on the basis of new geologic and paleontologic data presently available and differs considerably from the earlier sections given by Skorokhod and Prinada.

In the upper Amur basin, the freshwater-continental deposits lie with perfect conformity and gradational contact on the Upper Jurassic marine sediments. They are represented by 1400 to 5000 meters of sediments with very variable facies. In many different downwarps this sequence can be rather clearly divided into a series of formations and subformations (Fig. 2).

In the upper course of the Amur River, the freshwater-continental deposits are coal-bearing, but their coal content is extremely irregular and does not persist for any distance either parallel to or across the strike.

The coal-bearing sediments of the northwest-trending Amur downwarp (Upper Amur region) continue without interruption into the Amur-Zeya downwarp, which trends northeast and almost east-west at its northern end, and constitute a single large Amur-Zeya coal basin in which the coal content, the thickness of the coal beds, and their position in the section are very variable. Between the Amur and Zeya Rivers the coal-bearing sediments of this basin are covered by unconsolidated Tertiary sediments as much as 115 m in thickness. At present only the uppermost beds of the Lower Cretaceous freshwater-continental complex which are rather poor in coal (the Verkhnemolchansk formation) have been penetrated by drillholes.

Comparison of stratigraphic sections of the upper Amur River, the Ol'doy and Amur downwarps, the Zeya-Dep region (Amur-Zeya downwarp) and the Bureya River basin, based on paleontologic and lithologic characteristics, indicates a great variation in the facies and thicknesses of the freshwater-continental deposits in these regions due to the peculiarities of the structural development of the great Mesozoic downwarps.

The thickest freshwater-continental deposits accumulated in the Amur (4000 m) and in the Amur-Zeya (5000 m) downwarps parallel to the boundaries of the ancient Gonzhinsk salient and the Tukuringro-Dzhagdinsk anticlinorium in the southwest, southeast and south. These predominantly terrigenous sediments accumulated in mobile, intermont basins.

The terrigenous sediments, ranging from the finest clay and silt to coarse conglomerate and fanglomerate, are locally interbedded with pyroclastic beds and flows. Along the northern boundary of the Amur downwarp and the Gonzhinsk salient, felsite flows and tuff occur among the sediments only in the lower part of the section (at the base of the Osezhino formation). In the more mobile Amur-Zeya downwarp, which has the form of a broken letter S (Fig. 1), siliceous tuff, sandy tuff and tuffaceous sandstone are found throughout the section, beginning with the upper part of the Ayak formation, and reduce the quality of the coal.

Pyroclastic beds are especially abundant in the uppermost or Verkhenemolchansk formation. The saturation of the Upper Mesozoic sediments with volcanic materials in the Amur-Zeya downwarp is due, apparently, to the peculiar structural position of this downwarp along the zones of deep faults which form the boundary of the Tukuringro-Dzhagdinsk uplift and the Gonzhinsk salient on the south, and which served as the channels for the rise of volcanic materials. Still greater difference in

composition and in structural position of Jurassic and Lower Cretaceous sediments in comparison with the Upper Amur region is observed in Eastern Transbaikalia [6].

The available paleontologic and paleobotanic material is small, but adequate to subdivide the freshwater-continental deposits of the upper Amur region into the transitional Upper Jurassic - Lower Cretaceous and Lower Cretaceous units. Satisfactory correlation of stratigraphic sections of the Zeya-Dep region and the Bureya River basin has been made on the basis of plant remains and the freshwater fauna (Table 2). It is interesting to note that in these regions plant remains and spore-pollen assemblages, which according to Vakhrameyeva and Bolkhovitinova indicate an Early Cretaceous age, are found together with representatives of the genus Ferganoconcha, which in Martinson's opinion [5] did not survive in Transbaikal beyond the Late Jurassic. Inasmuch as paleobotanic evidence in these regions agrees well with the finds of an Upper Jurassic marine fauna in the El'Ginsk and other formations which underlie the coal-bearing sediments conformably [13], it is evident that the stratigraphic position of the genus Ferganoconcha in this region is somewhat different from that in Transbaikal and that some of its species, i.e., F. jorekensis Tshern. and F. burejensis Tshern., flourished in Early Cretaceous time.

The foregoing revision of the age of extremely complex and interesting deposits of Mesozoic freshwater-continental and marine sediments in the upper Amur basin undoubtedly needs further refinement and confirmation by analysis of additional paleontologic and paleobotanic collections, especially for the lower part of the section, the Jurassic marine sediments.

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FACIES AND CHEMICAL COMPOSITION OF THE TRACHY-BASALTS OF THE SAYAN-BAIKAL HIGHLANDS

by

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The paper discusses the distinctive features of the Sayan-Baikal trachybasalts. In the author's opinion these rocks include pyroclastic, extrusive flow and hypabyssal facies. They may be subdivided according to their chemical and mineralogic composition into the trachybasalt-soda shikhlunite(?), essexite-crinanite-limburgite and olivine basalt ("plateau basalt") groups.

* * * * *

INTRODUCTION

The Cenozoic intermont basins of the Sayan-Baikal highlands to which the trachybasalts are genetically related "may be tentatively considered synclines combined with rift structures of the South African type, developing on the margin of the Siberian platform within the ancient basement" [20, 22, 23].

The late Mesozoic continental deposits in this region form narrow subparallel bands trending southwest-northeast and are commonly accompanied by rather strongly altered Mesozoic extrusives. The bands are very long (300 to 400 km) and include the ranges separating adjacent basins as if they were links of a single chain. The bands come close together in the south and spread apart in the northeast, in the Vitim-Olekma highlands.

According to N. A. Florensov these Cenozoic structures concentrated in the northern and northwestern part of the highlands are quite distinctive from yet related to the Mesozoic structures. The Cenozoic system of basins of the Baikal type lies on the marginal zone of the Siberian platform and follows the bend of its folded border.

The distinctive tectonic development of the region during the late Mesozoic and through the Cenozoic resulted in accumulation of continental sediments and sedimentary-volcanic complexes in the basins and of thick pyroclastic basalt deposits unaccompanied by contemporaneous sediment on the crests.

In recent years new manifestations of Mesozoic-Cenozoic volcanism in Western Transbaikalia have been discovered such as the presence of post-Lower Cretaceous acid, subalkalic and alkalic intrusives whose connection with the latest tectonic cycle is obvious beyond the shadow of a doubt. The igneous rocks genetically related to the Mesozoic-Cenozoic subplatform cycle are listed in Table 1.

The Eastern Sayan Range and the Tunkinsk basin system contain mainly pyroclastic and flow facies.

The Selenga region of Dauria and the Baikal highlands contain mainly the hypabyssal facies represented by laccoliths, sills, stocks and dikes of crinanite, trachydolerite, essexite, essexite porphyry, monzonite, bostonite, ijolite, diabase porphyry, camptonite, labradorite porphyry, kersantite, malchite, etc. In the western part of the region, in the Dzhida River basin, Quaternary basaltic alkalic and calc-alkalic flows are widespread. The facies of the trachybasalts are given in Table 2.

Upper Cenozoic flows cover a large part of Eastern Siberia. Their western limit of distribution lies west of the town of Shagonar approximately on the 92nd meridian, their northern limit in Eastern Sayan passes through the headwater region of the Uda River towards the southern slope of the Okinsk Range, then through the Yerminsk Range towards the Torsk basin and farther northeast along Lake Baikal.

The age of the trachybasalt of the hypabyssal facies is partly determined by the fact that in the Selenga region of Dauria they

Table 1

Mesozoic-Cenozoic Igneous Rocks of the Baikal Sub-Platform Zone.

Formation	Facies	Age
Andesite-basalt (melaphyre complex)	Flows, pyroclastics	Mesozoic
Granitic (calcalkalic)	Hypabyssal rocks	
Granitic (subalkalic)	Hypabyssal rocks	Upper Jurassic -- Lower Cretaceous
Trachybasaltic	Flows, pyroclastics, hypabyssal rocks	Miocene -- Quaternary

Table 2

Trachybasalt Facies

Facies	Rocks	Types of igneous bodies
Pyroclastic	Tuff, tuff breccia, aa lava, agglutinate, lapilli tuff with and without bombs.	Cones, layers, small lenses.
Flows	Olivine, pyroxene, palagonite, zeolite, carbonatite, nepheline and analcime basalt, shoshonite, soda-shikhlunite.	Flows and complex beds.
Hypabyssal (depth of formation, 100 to 500 m)	Trachydolerite, dolerite, augite porphyry, essexite, essexite porphyry, ijolite, monzonite, nepheline syenite, camptonite, limburgite, crinanite, teschenite.	Laccoliths, stocks, cupolas, sills, dikes and dike swarms.

cut through Upper Jurassic and Lower Cretaceous continental deposits, i.e., they are post-Lower Cretaceous. They have not been found among Tertiary deposits.

The flows and pyroclastics fall sharply into two age groups, Tertiary and Quaternary.

M.L. Lur'ye [13] states that the Tertiary phase began with a small extrusion of basalt in Mongolia in the Oligocene. It is possible that the lower large flows overlying a great thickness of tuff in northeastern Tuva described by Lur'ye and S.V. Obruchev are also of this age.

The main mass of basaltic flows is Upper Tertiary. The age is established by the Miocene Flora found by Obruchev on the Tissa River in the tuff underlying the basalt. These basalts, called "plateau basalts," at one time covered considerable areas in Eastern Sayan south of the Okinsk Range and in the Khamar-Daban Range. North of the Okinskii Range there is a small remnant of a flow on the left bank of the Uda River near its tributary, the Khaylam River.

The following account is arranged in the sequence given in Table 2.

THE PYROCLASTIC FACIES

The outflow of Tertiary basalts was preceded in some localities by extrusion of pyroclastics and deposition of basaltic tuff. They are known at a few points in Eastern Sayan. V.N. Lodochnikov [12] described a 0.4 meter layer of tuff underlying basalt on the Taitorka River, the right tributary of the Yakut River, near the village of Shimka. Another occurrence is on the Mongol-Daban River, the right tributary of the Daban River. According to Florensov and Obruchev, the tuffs at this locality are up to 60 m thick and fill a depression in the Cambrian rocks to the level of an ancient valley floor and are covered by basalt flows.

Tuff occurs also on the Khulugaysh River (left tributary of the Irkut) in the Mondinsk basin. They form a cone (diatreme). This volcano was first described by Lodochnikov [11].

In the Tunkinsk basin, tuffs were found in a rotary drillhole in the lower part of the Tertiary (Miocene-Pliocene) sedimentary-volcanic sequence between 1470 and 2016 m. Six tuff beds were penetrated within this interval, ranging in thickness from 3 to 22 m.

According to the data of deep drilling available at present, the Tunkinsk basin contains the following rocks:

1. In the deepest parts of the basin, in the interval between 1,000 and 2,100 m. below the surface, normal sedimentary rocks are interbedded with the largest number of basaltic flows. The flows (over 65 in number) account for 600 m of the thickness of the fill, and the siltstone, sandstone and shale interbedded with them, for 500 m.

The lower volcanic-sedimentary group contains over six tuff beds with a total thickness of 75 m.

2. Higher in the section lies a 500 meter group of normal sediments without intercalated lava flows. This group is Neogene.

3. In the Quaternary sedimentary sequence, which is about 500 m thick, basaltic flows (12 flows) of different thickness (from 2 to 6 m) total 60 meters in thickness.

At the base of the Quaternary sedimentary-volcanic sequence, according to Florensov [23], lies a thick (200 m) group of tuffs and sandy tuffs with a few sedimentary beds.

Thus, two phases of Cenozoic volcanism can be distinguished in the Tunkinsk basin system; on the basis of available data, one is very late Tertiary and the other Quaternary (pre-Holocene, according to Florensov). The initial stages of these two phases were accompanied by violent explosive activity and deposition of thick masses of pyroclastics. The development of individual magmatic chambers passed through many stages.

Tertiary volcanoes are unknown in Eastern Sayan. Volcanoes of this age were described by Lur'ye [13] from northeastern Tuva and from the area between the Khamsary and Biy-Khem rivers. Here, basaltic tuff and tuff breccia 200 to 350 m in thickness lie on the lower lava flows, which have a total thickness of 100 m. The variation in the dips of the tuff suggests the existence of several volcanic cones, and the numerous bombs leave no doubt as to the nature of the eruptions. The eroded level surface of the tuff is covered by the upper basalt flows. Other pyroclastic deposits were found by E. E. Fedorov [25] in the middle part of Eastern Sayan (between the Ii and Uda rivers). Here pyroclastic layers up to 10 m in thickness are intercalated with flows at the base of the flow sequence.

Tertiary volcanoes of the central type were described by the author [3] from the basin of the Chika River (Bol'shoy Kumyn).

The Quaternary basalts belong to the second phase separated from the first by a long erosion cycle on the rising folds and by continued deposition of sediments in basins of the Baikal type (Tunkinsk basin system). This phase was much weaker, but basalt flows and small cinder cones are found in basins (Tunkinsk, Mondinsk), stream valleys (Oka, Dzhida, Darkhintuy, Bartoy rivers) and on the uplands (Vitim plateau).

The earliest manifestations of this phase, according to I. P. Rachkovskiy, Z. A. Lebedeva and S. V. Obruchev, occurred in northeastern Tuva, where basalt flows preceded the last glaciation. In Eastern Sayan and in the Khamar-Daban Range, the lavas of this phase are post-glacial, for they flowed around the moraines on the Dzhon-Balyk River (Oka River basin); on the Dzhida, Darkhintuy and Khamnei rivers, they are younger than the 20-meter river terraces, and in the Khuraytsakir basin and on the Khamney River they overlie the Dzhida River basalt. The lavas of the Darkhintuy River are covered by a layer of gravel, sand and soil, overlain by flows from the Bartoy valley and the Barun-Khobol gully, the left tributaries of the Darkhintuy River.

The northernmost region of Quaternary basalts lies on the Dzhon-Balyk River, the left tributary of the Oka River, and was first studied by P. A. Kropotkin. Later this region was studied by S. V. Obruchev [17]. Two volcanoes were found here, and on Obruchev's proposal were named Kropotkin and Peretolchin volcanoes. From the cones, which are up to 110 m in height, the flows descend for 70 km down the valleys of the Khikusha and Dzhon-Balyk rivers to the valley of the Oka River and dam it. Somewhat farther south on the Oka River near the villages of Orlik and Khara-Buzhir, two isolated basalt extrusions of the same phase were found. The cones are on top of the flow. They are composed of scoria, lapilli and bombs within an agglutinated mass. S. V. Obruchev [17] considers the Peretolchin and Kropotkin volcanoes to be of the Paricutin type (cinder cone).

V. N. Lodochnikov [12] was the first to find volcanic bombs near the hills in the Tunkinsk basin system and to prove the

presence of volcanic vents. He regarded the lava hills near the village of Talaya as remnants of a single volcano of the Hawaiian type. Florensov and Loskutova [21] concluded that "of the numerous lava mounds in the Tunkinsk basin, only two are small scoria cones (Svyashchennaya Gora and Ulyaborskiy volcanoes). The rest are fragments of larger cones rafted by the lava stream and only in one or two cases are they possibly spatter cones in situ."

Florensov [21] recognized three more or less isolated groups of scoria cones between the Akhalik and Irkut rivers within the Elovskiy spur: Khobok in the northeast, Kuntinsk and Talovsk in the west, and Akhalik in the southeast.

All these low hills and cones are of exactly the same composition, being built of scoriaceous basalt.

The volcanoes in the Tunkinsk basin vary in size but are in general rather small; their present height ranges from 40 to 50 m. The only high cinder cone is the Ulyaborskiy volcano (Kharabuldyk Range, northeastern end of the semi-arc nearer to the Tunkinsk chain of snow-covered peaks), which rises to 120 to 125 m.

The cinder cones between the Akhalik and Irkut rivers southeast of the village of Talaya lie on the left lava flow of the Yelovskiy spur, which dips gently towards the Tunkinsk basin. They have been largely destroyed and have lost their original form of regular truncated cones; but the composition of the scoria, agglutinates and coarsely vesicular lavas which compose them leave no doubt that they are analogous to the Peretolchin, Kropotkin, Svyashchennaya Gora and Ulyaborskiy volcanoes and the volcanoes in the Khuryay-Tsakir basin, the Barun Khobol gullies and on the Bartoy River.

West of the Tunkinsk basin is the small Mondinsk depression, elongated east-west. On its northern margin, in the Khulugayshi River system, lies a volcanic structure of diatreme or explosive vent type.

The main mass of the partly-eroded cone of the Khulugayshi volcano is basaltic tuff.

A continuous mass of tuff extends upstream for 400 m and on the left bank of the river on the southern and northern slopes of the diatreme, there are small outcrops of dense dark olivine-pyroxene basalt with well-defined columnar jointing. Very probably these basalts plug the volcanic vent. The tuffs are covered by Quaternary gravels.

Above the tuff lies a layer of almost unconsolidated agglutinates, and between them and the greenish-yellow tuff, an ash gray tuff later with lenses of very vesicular black scoria.

Among the tuffs there are round dense bombs with spheroidal jointing. They range in diameter from 15 cm to 60 cm and are composed of dense pyroxene basalt. The bombs contain well-rounded pebbles of granitic rocks and marble up to 5 cm in diameter.

THE FLOW FACIES

The basaltic flows are divisible into two age groups: 1) the Tertiary flows, the so-called "plateau basalts" lying on the divides of the domical uplift of the Eastern Sayan and Khamar-Daban ranges, the Vitim plateau and in the basins of the Baikal type (Tunkinsk basin) and 2) the Quaternary basaltoid lavas in the basins and river valleys, the so-called "valley basalts."

The Tertiary basalts contain, in addition to olivine, plagioclase, clinopyroxene and ore minerals, a rather considerable amount of zeolites and distinctive hydrous aluminosilicates of the palagonite type and are for this reason called palagonite basalts.

In the Tunkinsk basin among the Tertiary sedimentary and volcanic rocks, an iron-magnesium carbonate occurs in the basalt. These basalts are called here the carbonatite basalts.

In some Tertiary basalts the plagioclase crystals are rimmed with potash feldspar. In well-crystallized varieties of lava, the interstices between plagioclase grains contain small amounts of potash feldspar associated with zeolites and palagonite.

Four groups of rocks may be distinguished among the Tertiary and Quaternary basalts gradually passing into each other: 1) the holocrystalline medium-grained basalts, 2) the fine-grained basalts with a little glass, 3) the vitrophyric, often vesicular basalts and 4) basaltic glasses.

In the calc-alkali Tertiary basalts, olivine crystallized first, plagioclase and pyroxene second (the latter lagging a little), then came magnetite, apatite, zeolites, and finally palagonite, chlorite (pyrometacolloidal) and glass were formed.

The characteristic feature of the lava flows on the crest of the Sayan-Baikal highlands is the absence of sediments between the flows, of which there are twenty-six in

the Arlykgol'sk lava field and twenty-one in the Sagansarsk field.

Among the Quaternary trachybasalts the following varieties are present: olivine trachybasalt (with small amounts of potash feldspar), analcime basalt, lavas resembling shikhlunite (with soda sanidine as phenocrysts) and pyroxene and plagioclase basalts. Besides these there are black basaltic glasses (of the sideromelane type) containing small amounts of olivine, pyroxene and soda sanidine microlites.

The ejecta of the Bartoy group of volcanoes contain xenoliths of ultrabasic rocks composed of olivine, pyroxene and small amounts of soda sanidine, spinel and ore minerals.

Texturally, the basalts and trachybasalts may be divided into several groups; poikilophitic, doleritic, microdoleritic, intersertal, hyalopilitic and hyaline.

The basalt flows of the Bartoy group of cinder cones and of the stratified cone of the Barun-Khobol basin are alkalic; mineralogically and chemically they resemble the shikhlunite of Uyun-Kholdong and certain basaltic lavas of Darigang, China, but differ from them by having a higher soda content.

The phenocrysts of the Bartoy lavas are olivine, soda sanidine and pyroxene. The groundmass is composed of brown glass, relicts of resorbed olivine, pyroxene, soda sanidine and microlites of potash feldspar imbedded in the glass.

The texture is porphyritic, the groundmass is either hyalopilitic or hyaline.

The order of crystallization in these rocks is as follows: olivine, soda sanidine, pyroxene. Near the surface the only crystals are microlites of soda-potash feldspar, sodic plagioclase, clinopyroxene and titanomagnetite.

In the alkalic basic rocks only the olivine crystallized earlier than the soda sanidine and clinopyroxene, and the latter two crystallized almost simultaneously.

In the basaltic glass, only feldspar microlites are present; the microlites of pyroxene and the ore mineral are absent.

THE HYPABYSSAL FACIES

In the Selenga region of Dauria, in the Khilok basin filled with Mesozoic and Cenozoic sediments, on the right bank of the Khilok River in the vicinity of the Bichrusk ferry, and down the river opposite the mouth of the Mukhor River, dense aphanitic, black, basalt-like rocks were found by the author. These rocks form small dome-like elevations slightly elongated in the north-south direction and rising 80 to 120 m over the level steppe of the Khilok basin. The dimensions of the mounds at the present erosion surface are 1.0 x 1.4 km. Earlier these rocks were described as outcrops of East Siberian basaltoids [16].

Careful study of the basaltoids and of the morphology of the domes of the Khilok basin failed to disclose vesicular and amygdaloidal rocks so characteristic of the flows of the Sayan-Baikal highlands.

The rocks of the domes have three joint systems, the northeastern and northwestern, at about right angles to each other, and the system concentric to the surfaces of the domes. At the contact with the Upper Mesozoic deposits some basaltoids show spheroidal jointing. The Bichursk body preserves on its northwestern slope the remains of a roof composed of hornfels and recrystallized sandstone.

The basaltoids of the hypabyssal bodies contain dark-green crystals and clusters of olivine set in a dense, black groundmass. The groundmass, as seen under the microscope, consists of small strongly-elongated prisms of clinopyroxene with Wo = 43.6 percent, En = 46.6 percent and Fs = 9.8 percent, needles of plagioclase (An_{35-38}) and transparent, in some areas somewhat brownish, glass with numerous squares and point aggregates of an ore mineral. The ratio of the glass to the crystallized part of the rock is near 1:1.

In some sections the glassy groundmass exhibits barely noticeable anisotropism due apparently to the formation of the hydrous sodium aluminosilicate, analcime, as the result of devitrification. Sometimes among the grains of weakly birefringent analcime there are brown spots and radiated or sheaf-like structures indicating the change of analcime into natrolite.

A detailed microscopic and chemical investigation of the rocks [4] shows that these basalts are similar to the lumburgites of Lake Kivu in Central Africa and are somewhat more leucocratic than Zavaritskiy's average limburgite [7]. The hypabyssal dome opposite the mouth of the Mukhor River on the right bank of the Khilok River is composed of well-crystallized essexitic olivine dolerite containing basic plagioclase (labradorite), potash-soda feldspar (evidently soda sanidine), violet titanaugite, olivine and small amounts of red-brown biotite, an ore mineral and apatite.

The most idiomorphic are the olivine crys-
als in glomeroporphyritic clusters; the clino-
yroxene and the soda-potash feldspar occupy
paces among the plagioclase laths. The pot-
sh feldspar is xenomorphic and biotite ap-
ears at its contacts with the ore minerals.

The height of the Mukhorsk dome is 96 to
00 m above the Khilok River; its dimensions
t the present erosional level are 1.2 x 1.4
m.

In the northern part, near the edge of the
alley of the Khilok River, the dome is cut
y a dike of coarse-grained essexite. The
ike is about 3.0 m thick.

In the western part of the Khilok basin, on
e left bank of the Torgunok River, 1.3 km
orthwest of Lake Ambon, a dome 82 to 85
high rises above the level of the steppe.
is composed of dense black aphanitic py-
oxene rocks resembling leucocratic limburg-
e.

The rocks of the dome contain 50 to 60
ercent light-brown glass. There are no
liated or vesicular varieties among them.

The dimensions of the dome in plan do
ot exceed 0.8 x 0.9 km.

The most interesting of these structures
the dome of the Malyy Kumyn Mountain. It
es on the north-south segment of the Chikoy
iver, 4 km east of its floodplain. The dome
elongated to the northwest, its length is
4 km, its width, 1.1 km, and its elevation
about 120 to 130 m above the present
rosion level, or 782.8 m above sea level.

The dome is composed from base to top
fine-grained, dark-gray dense olivine
achydolerite. In some outcrops, the rocks
e platy but locally, probably at the con-
cts, they exhibit pillow or spheroidal joint-
g. The flat summit of the Malyy Kumyn
ome, with an area of 250 x 300 m, has a
pe-like depression with almost vertical
alls, measuring 75 x 80 m in area and 1.5
2.0 m in depth. The walls of the pipe and
s bottom are composed of very vesicular
assy, light-gray and red-brown "cinders"
scoria (spumolites, according to Zavarit-
iy). A shaft was sunk at the contact be-
een the vesicular and dense trachydolerite
the depth of 16 m without penetrating
rough the vesicular rock. No pyroclastics
flows have been found in the vicinity of
e Malyy Kumyn dome.

The rocks of the dome are composed of
ivine, plagioclase, clinopyroxene, potash
ldspar and small amounts of biotite, an
e mineral, and apatite. Their texture is
bophitic to ophitic.

The hypabyssal alkalic basic rocks, teschenite, and essexitic diabase were first described from the upper Angara depression by E.P. Moldavantsev [15], teschenite from the Kizhenga River, by E.A. Nechayeva [1], essexite porphyry, diabase, proterobase and camptonite from the Vitimkansk region, by V.K. Kotol'skiy [9]. Later, S.D. Sher [24] and L.I. Salop described exxesite, theralitic and essexitic diabase, olivine essexite porphyry, leucocratic essexite and essexite aplite from the same region. A.A. Konev and V.A. Lisiy [8] studied mineralogically unusual rocks of the covite, ijolite and nepheline syenite types from the upper basin of the Vitim River where they occur in stocks among ancient igneous rocks. The author [3] was the first to describe the lacoliths and sills of the Borgoy basin, which are composed of crinanite and their leucocratic varieties.

One of the large alkalic basic laccoliths was studied by the author in 1954 near the mouth of the Temnik River. It is oval in plan and elongated to the northeast, its width is 2.4 km, its length, 6.7 km and it rises 130 to 140 m above the level of the Temnik River. At the northeastern end of the laccolith there are "hot" contacts with the Jurassic-Cretaceous deposits of the Gusinoozersk series. The essexites are composed of olivine, clinopyroxene (titanaugite), calcic plagioclase, potash feldspar and small amounts of biotite, apatite and ore. The texture of the rocks is ophitic or subophitic at contacts. The same rocks were described from the northern part of the Borgoy basin, where in the form of dikes they cut through the lower beds of the Gusinoozersk series.

The shape of the basic alkalic hypabyssal bodies is very varied. In the basins filled with Mesozoic and Cenozoic sediments there are laccoliths and sills. In the transitional areas between basins and ranges there are mainly dikes (Selenga region of Dauria). In the ranges of the Baikal highlands and in Eastern Sayan there are stocks, lenses and dikes, the dikes trending northeast in the first region and northwest in the second.

The basic alkalic rocks in the Sayan-Baikal highlands have been variously dated; for example. A.A. Arsen'yev and Ye.A. Yechayeva [1] refer the teschenite (crinanite) from the Kizhenga River to the Cenozoic, but in another paper [2], they assign the camptonite, essexite porphyry and teschenite of the Baikal upland to the Proterozoic. The same complex was referred to the Caledonian magmatic cycle by Salop [18].

At present it may be said with assurance that in the Selenga region of Dauria, some of the trachybasalts are as young as Lower Cretaceous, for they cut through Jurassic

and Lower Cretaceous deposits. All doubts in connection with this problem are removed by the presence of metamorphosed sandstone of the Gusinoozersk series at the contact with the crinanite laccoliths of the Borgoy basin, the essexite laccolith in the northwester part of the Gusinoozersk basin, the bostonite stock on the southeastern shore of Gusinoe lake and at the heads of the Ara-Ganga and Khultuk-Dzhalga gullies, where greenish, strongly porphyritic bostonite (with anorthoclase phenocrysts) cuts through and alters Lower Cretaceous deposits which lie stratigraphically higher than the bituminous shale of the "Fish" formation with a Turginsk fauna [23].

At the contacts of these bodies with Cretaceous sandstone, there are crustiform structures in the sandstone cement, zeolites, analcime, biotite and titanomagnetite; the feldspars are replaced by a fine-grained quartz aggregate, and veinlets of phlogopite, carbonate and zeolites are also present.

Numerous facts point to the fact that even the uppermost (Lower Cretaceous) of all Mesozoic formations in the region have been directly affected by the emplacement of laccoliths, dikes, stocks and sills composed of alkalic and sub-alkalic rocks. The upper age limit of these rocks is not known.

CHEMICAL COMPOSITION OF THE TRACHYBASALT ASSOCIATION

At present, there are sufficient chemical data to draw a series of variation lines for individual age groups of the basaltoids of the Sayan-Baikal highlands. Many chemical analyses of the natural trachybasalt association, when plotted as a single variation line, reflect its variety without throwing light on the causes of variation. An attempt was made, therefore, to arrange all chemical analyses into age groups and to place all hypabyssal rocks in a group of their own. Then, using the statistical method, average vector types were computed in terms of Zavaritskiy's coefficients [6] for each age group, with reference to coefficient b, and variation lines were obtained which serve as median lines of the bands representing all chemical analyses of each age group. Table 3 presents the result of recalculation of chemical analyses to Zavaritskiy's coefficients.

It is very interesting to compare the chemistry of the trachybasalt formation of the Sayan-Baikal highlands with that of the alkalic rocks of the Far East and with the Pacific calc-alkali rocks represented by the lavas of Japanese volcanoes.

The variation diagram of Fig. 1 presents such a comparison of chemical characteristics of natural associations of basaltic lavas. These are: 1) Tertiary flow basalts (variation line I), 2) Quaternary flow basalts (variation line II), 3) post-Lower Cretaceous basic alkalic hypabyssal rocks (variation line III), 4) average variation line for the trachybasalt association of the Sayan-Baikal highlands (variation line IV), 5) lavas of the Far East from the mainland of Asia (variation line V) and 6) lavas of Japanese volcanoes (variation line VI). The vectors of composition and variation lines for the last two associations were plotted from Zavaritskiy's data [6].

In examining the variation diagram, we note, first of all, that it shows very clearly the characteristics of the serial grouping of rocks so well presented by Zavaritskiy [6]. The diagram shows that the Sayan-Baikal young rocks form a series whose parameters b and a differ from those of the Pacific calc-alkalic rocks of Japanese volcanoes and from the rocks of the East Asia alkalic province first defined by T. Tomina.

The diagram shows serial distribution of individual age complexes of the trachybasalt association of the Sayan-Baikal highlands. The Tertiary flows are of calc-alkalic type, whose variation line (I) continues the calc-alkalic series of Japanese lavas but differs from them in having a higher b parameter and feldspar lower in line. Hence the low value of c even in the more leucocratic members of the Tertiary series and in the melanocratic rocks of the Japanese volcanoes and the corresponding nearness of the origins of vectors on the CSB projection and axis AB. It should be noted that the Tertiary calc-alkalic series of the region is sodic but has a fairly high content of potassium aluminosilicates, while the calc-alkalic lavas of Japanese volcanoes are more sodic and contain relatively little potassium in their aluminosilicates (Japanese lavas make a smaller angle with axis SB on the CSB projection).

Thus, the comparison of the Tertiary calc-alkalic Sayan-Baikal series with the calc-alkalic series of the so-called Pacific province typified by the lavas of Japanese volcanoes shows that the former is a more basic series and differs sharply from the latter. This, it may be supposed, is due to dissimilar conditions of formation including difference in the depth of magmatic chamber which gave rise in the upper structural level of the crust to these two calc-alkalic series different in chemical and mineral composition.

The Quaternary lavas of the region have a much higher content of alkali aluminosilicates, and this is indicated on the diagram

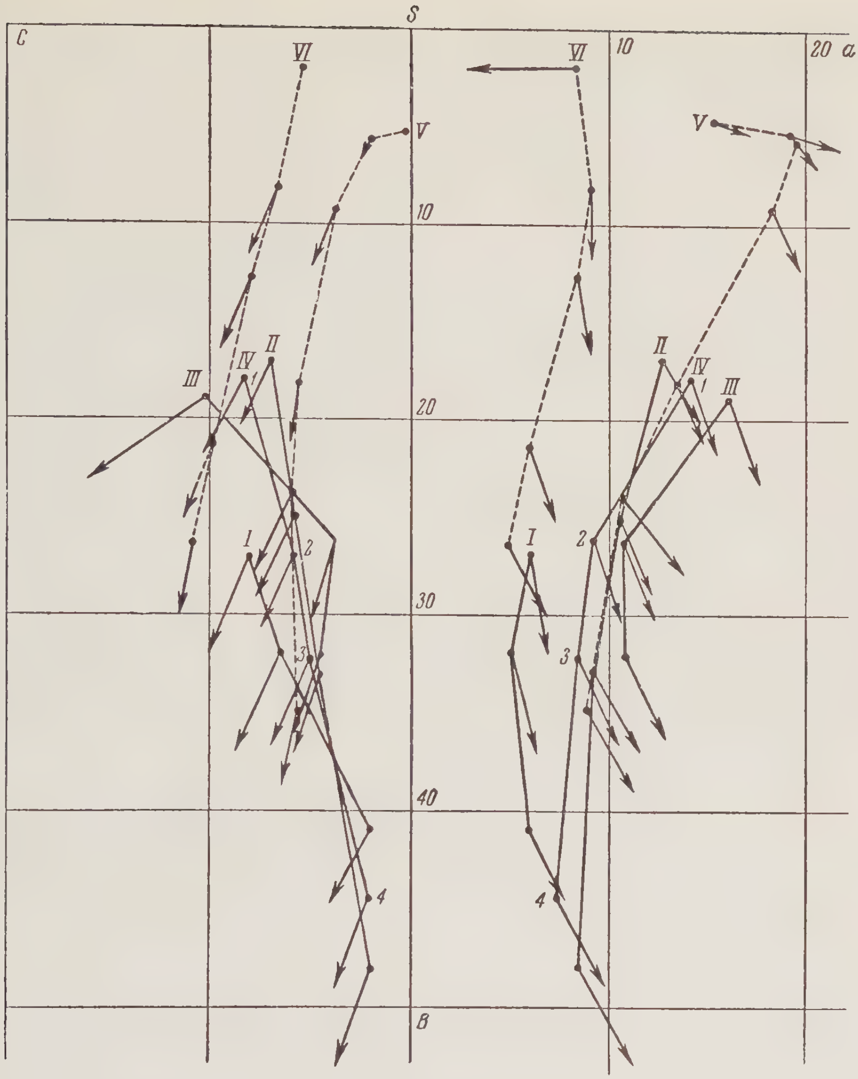

Fig. 1. Variation diagram of the natural association of basaltic lavas of the Sayan-Baikal highlands.

I -- Variation line of the Tertiary lavas; II -- variation line of post-Lower Cretaceous basic alkalic hypabyssals, III -- variation line of Quaternary flows; IV -- variation line (average type) of the Sayan-Baikal trachybasalts, V -- variation line of the Far East lavas, VI -- variation line of Japanese lavas.

by a strong shift of the variation line (III) and the vectors of the ASB projection to the right, as compared with the variation lines and vectors of the Tertiary calc-alkalic rocks of the same region and the Far East lavas described by T. Tomina (V). They are also more leucocratic as compared with Tertiary lavas and it is remarkable that in the more leucocratic members of the Quaternary series, parallel with the increase in alkali (parameter a) the lime content of the feldspars (parameter c) also increases and sodium is the dominant alkali metal.

The hypabyssal post-Lower Cretaceous rocks occupy an intermediate place between Tertiary and Quaternary lavas and, as the diagram shows, are almost exactly like the melanocratic branch of the alkalic lavas of the Far East (line II). But again the Sayan-Baikal series is more melanocratic. Cretaceous hypabyssals are soda-potash rocks, but those of the Far East are essentially sodic, and this is reflected in the angles between the vectors and the axis SB on the CSB plane.

The variation line (IV) which represents

Table 3

Parameters of the Average Types of Vectors for Tertiary and Quaternary Lavas and Hypabyssal Rocks of the Sayan-Baikal Trachybasaltic Association

	a	c	b	s	f'	m'	c'	n	Q	Number of Analysis
Post-Lower Cretaceous basic alkalic rocks (hypabyssal)										
1	12,6	7,0	17,0	63,4	59	33	8	69	— 5,4	15
2	10,5	5,8	25,2	58,5	43	40	17	68	—10,0	32
3	9,1	4,7	33,0	53,2	38	40	22	69	—16,5	18
4	8,3	2,1	48,1	41,5	22	50	28	76	—35,7	3
Tertiary basaltoids (flows)										
1	6,0	8,1	27,0	59,0	42	50	8	71	— 3,2	24
2	5,0	7,0	32,0	56,0	38	50	12	70	— 5,0	23
3	6,0	2,1	40,9	51,0	43	38	19	70	—12,0	6
Quaternary basaltoids (flows)										
1	16,0	10,3	19,0	54,7	43	42	15	42	—33,9	12
2	10,7	3,9	26,3	57,1	42	42	16	75	—11,1	32
3	10,7	4,6	32,1	52,6	38	42	20	76	—20,8	16

Table 4

Parameters of the Average Types of Vectors for the Sayan-Baikal Trachybasalt Association

Name of the average type	a	c	b	s'	f'	m'	c'	n
Essexite trachybasalt	14,0	8,6	18,0	59,3	51	37	12	69
Trachybasalt	9,1	5,9	26,2	58,8	42	44	14	70
Crinanite basanitoid	8,3	5,2	32,3	54,2	38	44	18	70
Limburgite basanitoid	7,2	2,1	44,5	46,2	32	44	24	73

the average composition of the trachybasalt association repeats the general chemical features of the Far East lavas, but only in the leucocratic part of the series, whereas the melanocratic branch contains somewhat less sodium, potassium, and calcium and more iron and magnesium.

For comparison with average composition of basic rocks of other regions of the earth and for determining the direction of magmatic differentiation, the average composition of each age group among the trachybasalts was computed, omitting water.

The Cenozoic igneous rocks of the region belong to three chemical groups, as shown by Tables 5 and 6 and Figure 2.

1. The trachybasalt-soda shikhlunite group (extensive flows). This group is represented by alkalic rocks which invariably contain olivine, calcic plagioclase, titanaugite, potash feldspar and, in some varieties, sodic sanidine, sodic plagioclase (in basic rocks), biotite and alkalic pyroxenes.

On the diagram (Fig. 2), the average composition of the Quaternary alkalic group occupies the extreme right position on the ASB plane, to the right of the lavas of the Far East.

Table 5.

Average Composition of Sayan-Baikal Basaltoids, by Age Groups

Oxides	1	2	3	4
SiO_2	47,00	47,86	48,81	47,13
TiO_2	2,24	2,26	2,34	2,61
Al_2O_3	16,24	15,90	16,55	16,23
Fe_2O_3	5,35	5,33	5 35	5,34
FeO	7,07	7,50	6,51	7,02
MgO	6,97	8,19	5,94	7,56
CaO	8,49	8,85	8,01	8,43
MnO	0,20	0,25	0,28	0,24
Na_2O	3,74	2,21	3,23	3,06
K_2O	2,04	1,08	2,17	1,76
P_2O_5	0,66	0,57	0,81	0,60
Total	100,00	100,00	100,0	100,00

The trachybasalt-soda shikhlunite group is not comparable to oceanic and continental basalts, Thulean plateau basalts, Tunguska basin traps or the Karroo diabase of South Africa.

2. The essexite-crinanite-limburgite group (hypabyssal). The varied rocks of this group are alkalic and subalkalic and correspond (according to averaged data) to the melanocratic branch of the Far East lavas.

On the diagram of lava types (Fig. 2), they occupy the extreme right and top position in the ASB plane, differing from the Quaternary alkalic basaltoids by the lower FeO, Fe2O3 and MgO content. This is due, apparently, to the process of assimilation of invaded rocks and crystal differentiation. Like the preceding group, this group is not identical in chemical composition with the average composition of the world basaltoids listed above.

3. The olivine basalt group ("plateau basalt," flows). This group is the typical representative of the calc-alkalic lavas of the Sayan-Baikal region and includes olivine, plagioclase, palagonite, carbonatite, and zeolite basalt. On the diagram of average types (Fig. 2, vector 2), Tertiary lavas occupy, on the ASB plane according to their value of b, an intermediate position between oceanic and Thulean basalts on the one hand and the Karroo traps on the other. They have a lower alkali content than the continental "plateau" basalts and a higher content of lime in the feldspars, and therefore the vector of the Tertiary lavas is shifted to the left on the CSB plane.

All rocks of this group contain olivine, calcic plagioclase and titanaugite. The spaces between plagioclase crystals are commonly filled with zeolites, palagonite, carbonate and sometimes potash feldspar, which also appears occasionally as rims on the calcic plagioclase.

The average composition of the rocks (vector 4) of the trachybasalt association in the Sayan-Baikal highlands occupies the

Table 6.

Geochemical Parameters of the Average Composition of Sayan-Baikal Basaltoids Compared with Those of Other Rocks.

No. on Fig. 2	a	c	b	s	f'	m'	c'	n	Q
1	11,1	5,4	28,1	55,4	40	41	19	74	−16,8
2	6,5	7,5	29,2	56,8	41	48	12	75	− 6,9
3	10,4	6,0	25,2	58,4	44	41	15	69	−10,0
4	9,0	6,4	29,1	55,5	38	43	19	72	−13,4
5	6,5	7,5	31,5	54,5	41	45	14	90	−12,5
6	8,3	4,7	29,0	58,0	43	30	27	75	− 5,3
7	7,8	5,4	30,4	56,4	40	38	22	81	− 8,2
8	5,9	8,0	27,5	58,6	44	36	20	84	− 2,6
9	5,8	7,3	26,8	60,1	40	44	16	80	+ 1,3

1 -- Quaternary basic alkalic lavas (flows); average of 60 analyses; 2 -- Tertiary basic calc-alkalic lavas (flows); average of 53 analyses; 3 -- Post-Lower Cretaceous basic alkalic rocks (hypabyssals); average of 60 analyses; 4 -- Trachybasalts of the Sayan-Baikal highlands, average of 181 analyses; 5 -- oceanic basalts, after Zavaritskiy [7]; 6 -- continental basalts, after Zavaritskiy [7]; 7 -- Thulean plateau basalts, after Daly [5]; average of 33 analyses; 8 -- traps of the Tunguska basin, after A.P. Lebedev [10]; average of 20 analyses; 9 -- Karroo diabases, after F. Walker and A. Poldervaart [19]; average of 43 analyses.

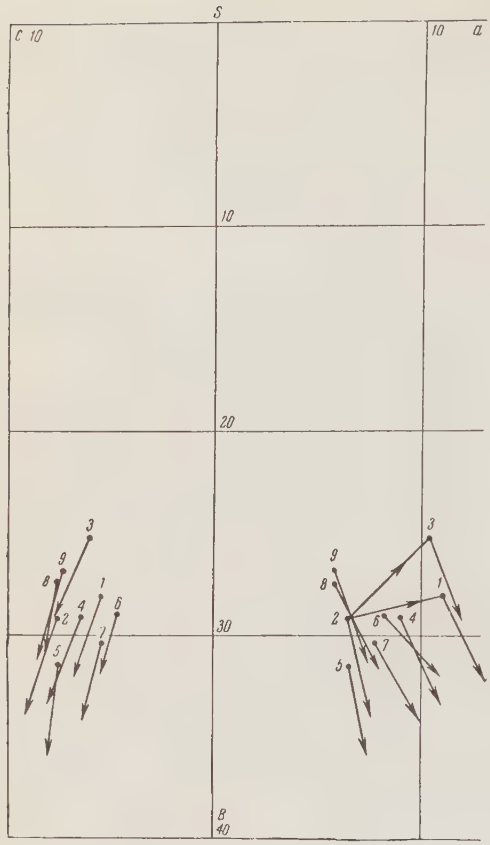

Fig. 2. Diagram of average types of Sayan-Baikal lavas.

1 -- Quaternary basaltoid lavas (average of 60 analyses); 2 -- Tertiary basaltoid lavas (average of 53 analyses); 3 -- post-Lower Cretaceous basic alkalic rocks (average of 68 analyses); 4 -- subplatform type of trachybasalt from the Sayan-Baikal highlands (average of 181 analyses), 5 -- oceanic basalt (after Zavaritskiy), 6 -- continental basalt (after Zavaritskiy), 7 -- Thulean plateau basalts (after Daly); 8 -- Tungus basin trap (after Lebedev), 9 -- Karroo diabase (after Walker and Poldervaart).

extreme right position on the ASB plane with respect to the average composition of some of the basaltoids of the world. It approaches the continental basalt type, which is less alkalic and contains much less lime in the feldspars, and so vector 4 is displaced to the left of the average composition of the continental "plateau basalts" (vector 6).

Thus, the average composition of the basic lavas of the Sayan-Baikal highlands indicates that this entire Cenozoic complex of rocks is trachybasaltic and is not comparable with the world basalts including the trap of the Siberian platform. It should be noted also that the earliest (Tertiary) lavas of this region are calc-alkalic and poorly differentiated (this is clearly shown on the variation diagram, Fig. 1), whereas the Quaternary lavas and hypabyssals are typical alkalic, sodic types.

The Tertiary lavas (Fig. 2, vector 2) are connected by lines with Quaternary lavas (vector 1) and with post-Lower Cretaceous hypabyssal rocks (vector 3), and this indicates the linear course of magmatic differentiation, primarily by crystallization, which the author believes led to the formation of these rocks. There is no doubt that, especially during the emplacement of hypabyssal rocks, the processes of assimilation of invaded continental rocks were also active.

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BRIEF COMMUNICATIONS

Apatite is an ever-present accessory in trap rocks. It usually occurs in acicular crystals in the mesostasis of such rocks as diabase pegmatite and albite. According to A. P. Lebedev [2] some diabase pegmatites contain up to 1 percent apatite. V. V. Lyakhovich found up to 2.86 percent apatite in the heavy fraction from the amygdaloidal diabase-gabbro of the Viluy region [3]. Apatite occurs sparsely as a minor mineral in the micropegmatitic mesostasis of pegmatoids and siliceous differentiates in basalt of the Union of South Africa [4], Deccan Plateau [1], Tasmania [5] and elsewhere. However, there is no mention either in foreign or Soviet literature of the presence in trap rock of postmagmatic apatite. Our investigations in the region of the middle course of the Lower Tunguska River furnish new material on this subject.

The region of the middle course of the Lower Tunguska River east of the village of Tur is composed of lava flows and basaltic tuff cut in many places by diabase dikes. Apatite occurrences are associated with coarse-grained olivine diabase dikes ranging from 50 to 100 m in thickness and cutting both flows and tuff. The enclosing rocks near these intrusives are considerably altered, which is not typical of the Siberian traps. The basalt flows are almost completely albitized, amphibolitized and zeolitized for tens of meters from the dikes. The rocks developed a secondary amygdaloidal structure with secondary magnetite, sulfides, epidote, sphene, zeolites and other minerals in the amygdules. The dikes are composed of coarse-grained olivine diabase containing olivine, clinopyroxene, plagioclase (55-60) and magnetite. The texture of the rocks is poikilophitic.

On the right bank of the lower Tunguska River, 73 km above the village of Tur, V. I. Kudryashova discovered apatite in a hydrothermal vein. The vein, 5 to 10 cm wide and 0.75 m long, lies 10 to 15 m from the foot wall of a thick olivine diabase intruded into the lava flows and following the columnar jointing of the dike (Fig. 1). At the contact with the vein, the diabase has an even coarser grained texture.

Along the periphery, the vein is composed of well-formed crystals of clinopyroxene (iron-rich diopside), magnetite and apatite; its central part consists of intertwined fibers of mesolite. The vein contains small amounts of analcime, chlorite, hydrous iron oxides and minute grains of sphene. The apatite fills about 5% of the vein.

The apatite crystals from this vein are honey-yellow prisms ranging from 0.7 to 2 cm in length. The crystals are uniform in habit and exhibit the following forms: (0001), (1010), 1120) and 1011) (Fig. 2). The prismatic faces have vertical striations which sometimes pass into vertical grooves and tubular corrosion channels (Fig. 3). The crystals are usually fractured and the fractures are generally coated with red-brown hydrous iron oxides. Some parts of the crystals contain gas bubbles.

The optical properties of the apatite are normal; i.e., it is uniaxial negative and its refractive indices determined by immersion are: $N_O = 1.647 \pm 0.002$, $N_E = 1.644 \pm 0.002$, $N_O - N_E = 0.003$.

The chemical analysis of the apatite is given in Table 1 (anal. 1).

At the mouth of the Turku River, small amounts of grayish-white, strongly elongated prisms of apatite (1 to 2 mm by 3 to 4 cm) were found in the pyroxene-magnetite-zeolite veinlets in an olivine diabase dike. The veinlets, only 2 to 3 mm in thickness, occupy joints in the dike. All minerals have a characteristic flattened crystal habit. The refractive indices of the apatite for sodium light are: $N_O = 1.648 \pm 0.002$, $N_E = 1.646 \pm 0.002$; $N_O - N_E = 0.002$.

The amount of this apatite available to us permitted only a spectrographic analysis.

The paragenesis of the minerals in the veins indicate that the apatite is of pneumatolytic-hydrothermal origin.

The apatite found on the left bank of the Lower Tunguska River differs genetically from the apatite described above, although

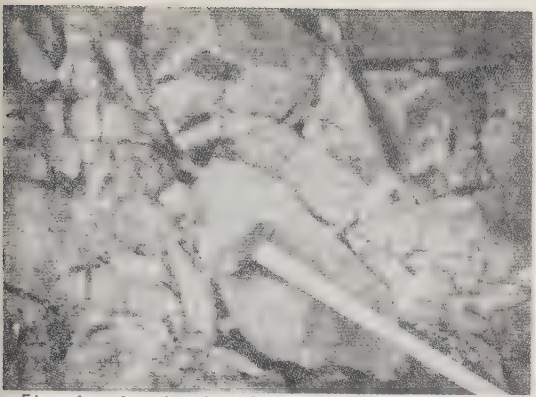

Fig. 1. Apatite-bearing vein in an olivine diabase dike.

Right bank of the lower Tunguska River, 73 km above the village of Tur.

the general geologic setting of all three occurrences is similar. Two types of apatite occur here in secondary amygdules of the strongly altered flows. Large crystals of apatite were found in a cavity filled with radiated zeolite and bordered by crystals of pyroxene and sphene. The apatite is transparent, light-green and occurs in elongated prisms 1 to 1.3 by 3 to 4 cm in size and having somewhat rounded cross-sections (Fig. 4). Its physical and optical properties are normal. $N_O = 1.647 \pm 0.002$, $N_E = 1.644 \pm 0.002$, $N_O - N_E = 0.003$. The alabite crystals are coated with a whitish crust of thomsonite.

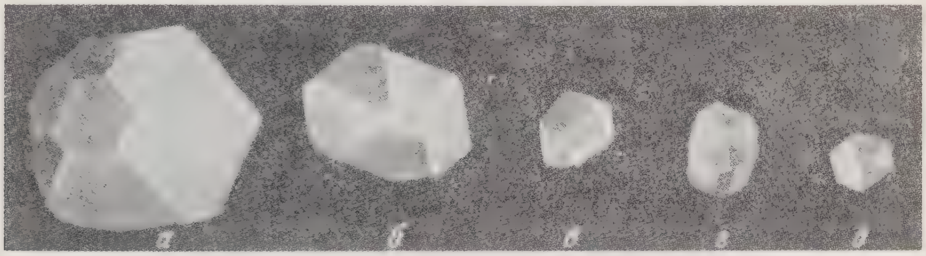

Fig. 2. Habit of the apatite crystals.

73 km above the village of Tur. Magnification: a -- 3X, b -- 2.5X, c,d -- 3X, e -- 4X.

The chemical analysis of this apatite is given in Table 1 (analysis 2).

The second type of apatite is much less abundant and occurs in bluish-white druses in amygdules ranging from 1 to 1.5 cm in diameter and in the same mineral association as the apatite of the first type.

The crystals of this apatite are prisms with hexagonal section, and the largest of them have diameters of 0.5 to 1.0 mm (Fig. 5). Its refractive indices are considerably higher than those of the previously described apatite: $N_O = 1.657 \pm 0.002$, $N_E = 1.653 \pm 0.002$, $N_O - N_E = 0.002$.

This apatite is so scarce that it was impossible to collect enough of it even for a spectrographic analysis.

Besides the already described apatite from the Lower Tunguska River basin, other occurrences have been described from the trap formation of Siberia.

A. P. Lebedev separated a magmatic apatite from the heavy mineral fraction of the diorite-pegmatite schlieren in a diabase sill (on the right bank of the Podkamennaya Tunguska River) intruded into carbonate rocks belonging to the Stolbovaya formation.

Apatite associated with pyroxene, garnet, ilmenite, sphene and zircon occurs in grayish-green prismatic crystals up to 1.5 mm in length and 0.5 mm in diameter. It commonly contains inclusions of ore minerals (i.e., magnetite and ilmenite). Its refractive indices determined in sodium light by immersion are: $N_O = 1.645$, $N_E = 1.640$, $N_O - N_E = 0.005$. Its chemical composition is given in Table 1 (analysis 3).

An apatite from the Kamyshevskiy Bakitik magnetite deposit has also been studied. According to N. V. Pavolv, this is a

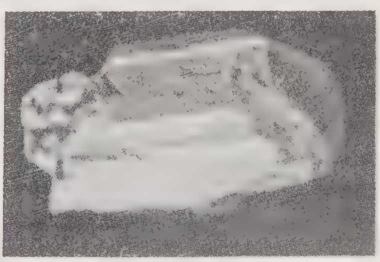

Fig. 3. Vertical striations and corrosion grooves on the prism faces of apatite from the same locality, 2.5X.

Table 1

Chemical Composition of Apatites from the Traps

Components	Lower Tunguska						Podkamennaya Tunguska					
	right bank, from a hydrothermal vein			left bank, from metasomatically altered flows			from diorite pegmatite schlieren			from the Kamyshevskiy Baykitik magnetite deposit		
	analysis 1			analysis 2			analysis 3			analysis 4		
	wt. %	mol. x 1000	ratio	wt. %	mol. x 1000	ratio	wt. %	mol. x 1000	ratio	wt. %	mol. x 1000	ratio
P_2O_5	40,92	5764	5789=6	40,89	5761	5,82	41.98	5916	6	41.17	5800	6
SiO_2	0,13	25		Not found	—		Not found	—	—	Not found	—	—
CO_2	Not found	—		Not found	—		»	—	—	0,82	—	—
CaO	52,92	9437		} 55,45			54,55	9727		} 54,98	9804	10,14
SrO	0,10	10			9888							
MnO	0,07	10	9769=10,12	Not found		9897=10						
TR	2,13	130					0,12	17	9854=9,99	Not found	—	—
Fe_2O_3	0,19	—		0,10	6		0,90	45		»	—	—
Al_2O_3	0,31	—		0,07	—		Not found	—		»	—	—
K_2O	0,05	11		0,13	—		0,15	—		»	—	—
Na_2O	0,53	171		Not det.	—		Not found	—		Not det.	—	—
H_2O	0,61	677	1780=1,84	»	—		0,20	65		»	—	—
F	1,20	632		0,36	116		0,35	389	1913	0,43	477	
Cl	1,67	471		2,35	1237	1903=1,92	2,60	1369	1,94	2,24	1179	1856=1,92
Insoluble				1,95	550		0.65	155	,	0,71	200	
residue	None			0,09	—		None			0,29		
Total	100,85	—	—	101,39	—	—	101,50	—	—	100,64	—	—
$-0=(F,Cl)_2$	—0,87	—	—	—1,41	—	—	—1,24	—	—	- 0,91	—	—
Total	99,98	—	—	99,98	—	—	101,26	—	—	99,73	—	—
Cl : (OH+F)	—	0,36	—	—	0,33	—	—	0,10	—	—	0,12	—
Cl : OH	—	0,69	—	—	1,37	—	—	0,47	—	—	0,41	—
Cl : F	—	0,75	—	—	0,44	—	—	0,13	—	—	0,16	—
Specific weight	—	3,276	—	—	—	—	—	3,316	—	—	3.126	—

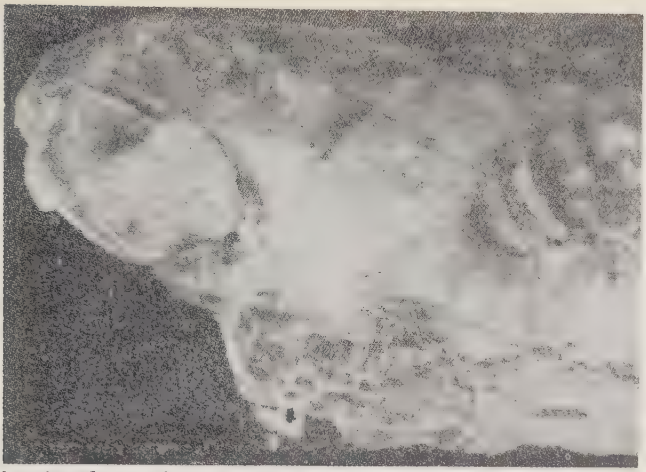

Figure 4. Apatite from a large cavity in altered lava flow at contact with a dike.

Left bank of the Lower Tunguska River, 55 km above the village of Tur; 2X.

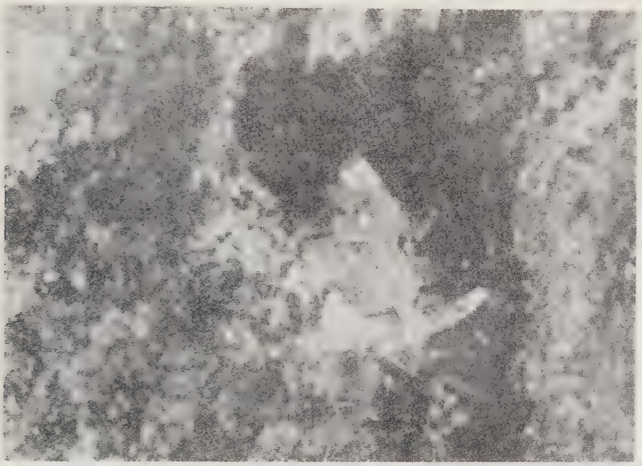

Figure 5. A druse of apatite crystals in an amygdule of an altered lava flow.

Same locality; 8X.

etasomatic deposit associated with a differ-ntiated diabase-gabbro complex. Very likely .e ore solutions here were related to the :id differentiates of basic rocks. The apa-te occurs in white acicular crystals. N_O = 648, N_E = 1.641, N_O-N_E = 0.007. The :e body, composed mainly of magnesian .agnetite, also contains chlorite and sparse ılcite and dolomite. The chemical analysis : this apatite is given in Table 1 (analysis 4).

The chemical analyses of the apatite were .ade by one of the senior authors, Z. V. asil'yeva, by means of ion-exchange resins ith active sulfonic groups which permit sep-:ation of cations and anions. In all cases, only very small amounts of material were available and it was impossible to make certain determinations.

As can be seen from the table, the difference in the rare earth content attracts attention first of all. The apatite from the hydrothermal veins and from pegmatite schlieren contains rather significant amounts of the rare earths (0.90 to 2.13 percent), but in the other two varieties of apatite (from metasomatically altered lava flows and from the magnetite deposit) they are absent. Spectrographic analysis shows that the rare earths are absent also from the apatite of the magnetite-pyroxene veinlets. Because of

lack of material no complete chemical analysis was made of this apatite.

The presence of the rare earths in the apatites is accompanied by the entry of sodium necessary to balance the valence. Because of the small total weight of the rare earth precipitate, it was impossible to separate the individual members of the group. A semi-quantitative, x-ray and chemical analysis shows mainly the presence of Ce and La, although the apatite from the diorite-pegmatite schlieren has also a rather high yttrium content.

Basic rocks are characterized by a relatively high chlorine content, but in spite of the fact that the apatite is genetically related to basalt, and other typical basic rocks, it does have a considerable Cl content; never-the less the Cl:(OH + F) ratio does not exceed 0.36.

All analyses show the presence of water, which is an essential component of this apatite. Nevertheless, fluorine is dominant in the apatite, and it may be classified as an F-OH-Cl apatite.

The presence of Fe_2O_3, Al_2O_3 and SiO_2 is due, apparently, to contamination. This is true especially of the apatite from hydrothermal vein (analysis 1) which, as the microscopic examination shows, contains very minute segregations of mesolite impossible to separate from apatite either by heavy liquids or by hand picking under a binocular. It is impossible also to separate calcite from the apatite of the magnetite deposit, whose analysis shows 0.92 percent of CO_2. The presence of impurities in these apatites is confirmed by recalculation of the analyses to the apatite formula (Table 1).

In the apatite from the metasomatically-altered lava flows (analysis 2), the presence of sulfur was determined by x-ray and chemical analysis. Lack of material made it impossible to make chemical determinations of sulfur but recalculation of the analysis shows that there is a deficiency of phosphorus as compared to the amount required by the apatite formula. Some of the phosphorus is evidently replaced here by sulfur.

On the whole, however, Table 1 shows th this apatite corresponds to the usual apatite formula, $Ca_{10}P_6O_{24}(F, Cl, OH)_2$.

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FROM THE HISTORY OF GEOLOGIC SCIENCES

MEMORIAL DATES FOR JULY-SEPTEMBER, 1958 REVIEW 22

HE TWO HUNDRED AND TWENTY-FIFTH ANNIVERSARY OF THE DEATH OF THE SWISS NATURALIST J. J. SCHEUCHZER

Johan Jakob Scheuchzer was born in Zurich August 2, 1672. He received a medical ucation in Altdorf and Utrecht and later acticed dentistry at Zurich while serving the same time as professor of mathematics d physics. He was the first in Switzerland make a serious study of the natural iences.

Scheuchzer's works devoted to the study of ssils are of great interest. During this itial period in the development of paleon- logy many investigators believed that fossils ere sports of nature, figured stones bearing perficial resemblance to existing animals id plants. Scheuchzer also held this view first, but geologic data in the literature id numerous personal observations led him the true concept of the nature of fossils. his works he described many fish, mol- sk, and plant remains, and other fossils of vitzerland and stated that they had been uried during the "universal flood". He was e first to describe the remains of a giant lamander which he found in the calcareous ale of Oeningen but mistook it for a human eleton, an error corrected later by Cuvier.

As the result of a detailed study of coal, heuchzer was among the first (1706) to con- ude that it was of vegetable origin. He be- eved that coal deposits were allochthonous id formed in the places of accumulation of ant debris deposited by streams.

Traveling in the Alps, he collected infor- ation about glaciers and published a work ith interesting observations on the causes glacier movement, viz., water seeping to the cracks in the ice expands on freezing id thus the entire mass of a glacier is set to motion.

Being a believer in the universal flood, Scheuchzer explained the origin of various landforms exclusively by the action of running water.

One of the largest of Scheuchzer's works is his Natural History of Switzerland (1708), in which one section is devoted to the description of fossils found in the rocks of that country.

Johann Jakob Scheuchzer died on June 23, 1733.

Steiger, R., VERZEICHNISS DES WISSENSCHAFTLICHEN NACHLASSES VON JOHANN JAKOB SCHEUCHZER, Vierteljaresschr. Naturf. Ges. v. 78, Zurich, 1933.

BICENTENNIAL OF THE FOUNDING OF THE FIRST ACADEMY OF MINES

On October 19, 1757, the first special mining school was opened for "public lectures and experiments in the field of underground geometry, hydraulics, hydrostatics and mechanics as well as metallurgy and the arts of assaying and smelting included in it" in the center of the Norwegian mining industry, in the town of Kongsberg.[1] The school had rooms for laboratory work and collections of minerals and rocks. It required four years of study and one to one-and-a-half years of practical work abroad.

The school was frequently reorganized, the course of study changed, and often there was a shortage of class rooms. During its flourishing period (1775-1785) it offered the following courses: mineralogy, theoretical and practical chemistry (including metallurgy, hallurgy and pyrotechnics), ore deposits, mine construction, mining law, drawing and others.

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[1] In the course of the following two decades other mining academies were established: at Freiberg (1765), in Berlin and Chemnitz (1710), in Petersburg (1773) and in Clausthal, Harz (1775).

The number of students was small but still it was the only institution of higher learning in Norway and the specialists trained in it became leaders in the domestic mining industry.

In 1811 when it was decided to create a university, the Kongsberg Higher Mining School was included in it. The university was opened in Christiana (now Oslo) and mining and geologic sciences became its leading subjects.

Hjortdahl, Th., BERGSEMINARIET PA KONGSBERG, Nyt Magazin for Naturvidenskaberne, bd. 45, 1907.

THE CENTENNARY OF L. A. YACHEVSKIY'S BIRTH

Leonard Antonovich Yachevskiy was born September 11 (August 30), 1858 in Kaliscz (Poland). He finished the Petersburg Mining Institute in 1883 and was immediately employed by the Chief Mining Administration and later by the Geological Committee.

Yachevskiy did his work mainly in the gold-bearing regions of Eastern Siberia. In the 1890's he participated in the surveys along the Trans-Siberian railway route and his studies embraced the extensive regions of the Enisei and Irkutsk governments as far as the watersheds of the Sayan Mountains and the Baikal Range.

Yachevskiy's principal works are devoted to regional geology and to the study of mineral deposits, mainly gold and salt. Besides this, he was interested in the problem of seismicity of Transbaikalia and in permafrost phenomena. Yachevskiy emphasized the importance of geothermal investigations and expressed original ideas on the thermal regime of the earth's surface. Through his initiative the International Geological Congress created a committee on geothermal research.

Yachevskiy's works in hydrogeology are widely known. He determined the relation between yield and diameter of wells. He wrote a number of papers on the genesis of mineral springs and made an important contribution towards the improvement of domestic balneotherapeutic resorts.

In all of his regional studies, Yachevskiy paid much attention to petrography. In his studies of rocks, he made wide use of microscopic and chemical methods which were just being introduced at that time. He described many minerals of Siberia, among them nephrite, jadeite, graphite, platinum, diamond, etc.

From 1899 to 1903, Yachevskiy served as Professor of Mineralogy at the Ekaterinoslav Mining School.

Yachevskiy died in Petrograd on May 3 (April 20), 1916).

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CENTENNARY OF THE BIRTH OF THE GERMAN GEOMORPHOLOGIST A. PENCK

Friedrich Karl Albrecht Penck was born on September 25, 1858, in Leipzig, and was educated there, finishing the University cour[se] in 1875. Three years later he was given the degree of Doctor of Philosophy by the University and in 1882 became docent at the University of Munich. In 1885, Penck became full professor at the University of Vienna, where he worked until 1906, when he moved to Berlin to take the chair vacated by the death of F. Richthofen.

Penck's first works were devoted to geology and mineralogy but he soon became attracted by the problems of geomorphology and physiography and devoted the rest of his life to these sciences.

During his long scientific career, Penck made many distant journeys. He visited Scandinavia, Western Europe, North and South America, Africa, Australia, Hawaii, Japan, China, Siberia, Southern Europe and the Balkans.

Penck's principal works are devoted to geomorphology and glaciology. One of the largest is his two-volume Morphologie der Erdoberfläche (1894), in which he synthesize[d] a mass of factual material on landforms. Much attention is given in this book to transitional forms, and their transitory characte[r] is emphasized. This work has many merits but also some rather important shortcomings. The relationship between geomorphic features and primary structures is lost and the origi[n] of these features is explained by accidental, logically and causationally unrelated factors.

The three-volume work, Die Alpen in Eiszeitalter (1909), written with E. Bruckner was of great scientific importance, for it initiated a new epoch in this branch of study. The duration of the Quaternary Ice Age was estimated in this work at about one million years. Penck showed that there were advances and retreats of ice and long interglacial stages. He developed the idea, based

n isotasy, that loading and unloading by ice an cause crustal movements.

Among the subjects which interested Penck ere the formation of karst, the desert mor- nology, the origin of glaciated topography nd the effect of eustatic movements of sea evel on the erosion of adjacent lands.

Penck did much editorial work. For a long me the Geographische Abhandlungen and a umber of other geographic periodicals were ublished under his guidance.

Penck's scientific achievements were widely cclaimed. He was elected active member of ie Vienna and Prussian academies, the Na- onal Academy at Washington, and honorary iember of the Edinburgh Royal Society; he lso received honorary degrees from a num- er of universities in different countries.

Albrecht Penck died in Prague on March 7, 945.

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SEVENTY-FIVE YEARS SINCE THE PUBLICATION OF E. SUESS' "THE FACE OF THE EARTH"

In 1883, separate issues began to appear Eduard Suess' monumental work The Face the Earth (E. Suess, Das Antliz der Erde, ι. I-III, 1883-1909). Vast materials on the ology of every continent were synthesized this work.

The first volume is devoted to the origin continents and mountains and an analysis geologic events throughout the history of e earth. The author shows that changes in e solid and liquid shells of the earth caused anges of paleogeographic conditions and of e face of the earth as a whole.

Suess discussed the "universal flood" in tail and showed convincingly that the basis r this biblical legend was a flood which tually covered a large part of the Near ist.

The greatest attention was given by Suess the geologic structure of mountain systems th the purpose of determining their history and pattern of development.

The main topic of the second volume is the development of oceans and their shore- lines, which Suess divided into two specific types, the Atlantic and the Pacific. In the same volume, the causes of secular move- ments of the earth's crust and the history of marine transgressions and regressions since the Paleozoic are discussed.

Suess was an adherent of the contraction hypothesis, and believed that as a result of compression marine basins subside periodi- cally and that this causes the lowering of the water level in the ocean.

The third volume is devoted to the struc- ture of Eurasia. Much space is given espe- cially to the continent of Asia. Suess used the most recent, unpublished data of Russian geologists given to him by V. A. Obruchev. He traced the principal tectonic lines which control the folded structures of the continent.

In the second part of the third volume, which is really an independent fourth volume, the principal tectonic trends of all continents are reviewed, island arcs are described and the zones of most intense volcanic activity are delineated.

In the final section, Suess touches upon fundamental problems of geology such as the internal structure of the earth, the character- istics of its surface development, the origin of life on earth and the relief of the moon.

Suess' The Face of the Earth revealed the regularities in the geologic development of the planet. It encouraged advances in many branches of geology (stratigraphy, tectonics, paleogeography, petrology and others). For several decades it was justly regarded as the greatest theoretical geologic syntheses and was translated into English, French and Italian.

The Face of the Earth was awarded gold medals by the Russian Geographical Society and by the Royal Society of London.

Obruchev, V. A. and M. I. Zotina, EDUARD SUESS. M. 1937.

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REVIEWS AND DISCUSSIONS

ON THE PROCESSES OF COALIFICATION[1]

D. T. Zabramny's is a specialist's report. I am commenting on it because by using the results of experiments in artificial coalification, the author disputes a number of geologic concepts and derives his own coal series. In Zabramny's opinion, the geologic two-stage concept of coalification does not agree with the chemical data. He justly points out (p. 84) that "only those theories of coal formation approach truth that consider both the geologic and chemical factors."

Zabramny's experiments must also be considered with this point of view in mind.

In the series of experiments on coalification under anaerobic conditions (Table 1), one notices that for the dry long-flame coals from Kok-Yangaka, an imperceptible increase in carbon (less than 1%) was accompanied by too great a decrease in volatiles (from 40 to 24%), almost to the level of the volatile content in coking coals. It is likely that the process which had taken place in the experiment is not the same as in nature.

According to Table 2[2] the sample from Sulyukta, a brown coal, was composed mainly of fusain, judging by the content of volatiles. Fusain is an inert substance which changes little (but nevertheless changes) during coalification. The bituminous coals show a sharper decrease in volatiles than the increase in carbon would warrant, which again speaks against the identity between artificial and natural coalification. More likely a process to some extent similar to carbonization (fusinization) occurred here. Naturally, none of these artificial products cokes.

Very interesting are the coalification experiments with previously hydrogenated coal. The sample used was of a long-flame coal (Kok-Yangak?). It was hydrogenated for four hours. Artificial coalification was performed under aerobic and anaerobic conditions. The results are shown in Table 5, which is reproduced in full.

Zabramny made one correct deduction from this (point 2), that in these experiments long-flame coals yield products "which in their chemical composition, volatile content and coking properties do not differ from natural high volatile steam and coking coals" (p. 21).

But another conclusion can be made, and that is that in nature, in an anaerobic environment, a process very similar to these experiments takes place under reducing conditions; the nature of this process is still unexplained.

According to Zabramny, "Any coal may be artificially converted to coking coal" (point 3), and this is an important step forward. The experiments show that under certain conditions (reducing environment, hydrogeneration) coking qualities may be obtained or increased under laboratory conditions. Why, then, are they not obtained or increased in the course of natural coalification?

In the laboratory this requires a preliminary enrichment in hydrogen.

But cannot such enrichment occur in a coal bed during the process of coalification or even earlier, in the peat bog? The discovery by D. I. Bogolyubova at the Donets Coal Institute (DONUGI) of two types of coals "reduced" to a different degree, shows that even the long-flame coals of the "reduced" type have a plastic layer (for example, y-5) of some thickness. The initial properties of the peat must, therefore, be significant.

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[1] These comments apply to D. T. Zabramny's paper, The Processes of Coalification, presented at the Second All-Union Conference on Coal and printed in the Proceedings of the Laboratory of Coal Geology, v. 6, 1955. This article by Yu. A. Zhemchuzhnyy and his paper on the Similarities and Differences between facies, Cyclothems and Structural methods of the Study of Coal Beds, printed in Izvestiya, Akademiya Nauk SSSR, Ser. Geol., no. 1, 1958, were completed in December of 1958 and were received by the Editors after the death of the author in February 1957.

[2] The numbers of tables here coincide with those in Zabramny's paper.

Table 5

Coalification of Hydrogenated Coal

Material (coal)	Conditions of experiment	Duration of coal-ifica-tion (hrs)	Temperature of coalifi-cation (^{o}C)	V (%)	Character of coke pellet	C (%)	H (%)	Degree of coali-fication
Natural	--	--	--	42, 6	Agglutin-ated	77, 8	5, 0	Long-flame coal
Hydrogenated	--	--	--	53, 1	Fused coked swelled	81, 7	6, 2	
Hydrogenated artificially coalified	Aerobic	9	325	36, 1	Fused coked unswelled	83, 6	5, 6	Fat steam coal
	Anaerobic	7	360	26, 0	Coked silvery	85, 5	5, 3	Coking coal

But y, nevertheless, increases during :oalification. It is unfortunate that Za-ıramny did not measure y in the artificial .oals; y increases in the different experi-nents up to the middle of the metamorphic eries.

It has always been believed that fusain .oes not coke in any coal, that individual-zed vitrain cokes better than the matrix, hat the xylo-vitrain and xylo-vitrain matrix .oke better than the homogeneous matrix this became especially clear after Bogolyu-ıova's work). However, coking practice hows that in all principal coal basins, the .oal with the highest coking properties highest fusibility, etc.) belongs to an in-ermediate stage of coalification.

The first point in Zabramny's conclu-ions states that, "Modern peats, brown nd long-flame coals do not have these :oking properties, not because they belong o an early stage of coalification but be-ause they formed in a medium with insuf-iciently high reduction potential" (91).

Of course, such a thought can be ex-ıressed only as a hypothesis, for it does ıot follow directly from Zabramny's experi-nents. For example, it cannot be applied o peat, because we do not know at present ıf a single coking peat. Humic brown coals lo not coke whatever their age (Carboni-erous, Permian, Jurassic or Tertiary). 'usain coals do not coke.

It is curious that among the bituminous :oals of all these ages, including the Ter-iary, bright coals with gel substance coke :ven if they belong to the middle stages of coalification. No bright coals with 26 to 35 percent of combustible volatiles (V) are known which do not coke.

Therefore in Zabramny's Table (repro-duced here) the series which manifests those characteristics demonstrating the author's views, peat -- long flame coal -- gas coal -- fat steam coal -- coking coal -- lean coal -- anthracite, is a geologic im-possibility for amorphous coals unless it is restricted to the fusain-xylinites. This is an artificial series which does not occur in nature. It is not clear why brown coals are omitted from the series.

The lower series, peat -- brown coal -- metamorphosed brown coal -- anthracite, is not clear. If the last coal type is brown, then why is it metamorphosed and what is the nature of its metamorphism? And does it change directly to anthracite? What are the criteria?

The series also has a slight branch from peat to gas coals.

It is unfortunate that Zabramny does not give an example of this strange evolution in nature. If this is only experimental, then the products are not really quite like gas coals. The carbonvolatiles ratio is different and the product does not fit any natural rank of coal.

Finally, there is the main (upper) series: peat -- fat steam coal -- coking coal -- lean steam coal -- anthracite. The jump from peat to fat steam coal with omission of long-flame and gas coals is strange. The author based this series on experiments

with hydrogenated long-flame coal. But one or a few experiments are not enough to arrive at such far-reaching conclusions.

How is it to be explained that in nature, where a broad series of bright coals exists (Donbas, Kuzbas, Karaganda, etc.) there are always long-flame and gas coals arranged in zones together with fat steam and coking coals?

Elsewhere, Zabramny expressed a firm conviction that long-flame and gas coals in these basins are weathered fat steam coals. As a coal chemist he knows well that weathered coals have a number of physical and chemical properties which distinguish them from unweathered coals (N. M. Karavayev, T.A. Kikharanko and others). He could have checked his hypothesis and become convinced that apart from lower agglutinating value these coals show no other signs of weathering.

It is unfortunate that in presenting his scheme, the author did not document it sufficiently and did not cite examples to show how it agrees with chemical and geologic data -- a requirement which he himself requires of a true theory.

The author presents a number of objections to the generally accepted coal series. But some of these objections are based on misunderstandings. The first objection is that the coal series cannot explain the decrease in oxygen content during the change from brown to bituminous coal. But the same decrease continues in the bituminous coals all the way to anthracite (2.3 percent). Both of these phenomena must be explained by coal chemists themselves and for this purpose they must reconstruct the whole picture of metamorphism.

According to his point c, the author finds many contradictions in the geologic concept of coking. Let us cite the entire paragraph, for it contains many inaccuracies: "c) The series is basically contradictory, for, on the one hand it is considered that the vitrinized substances which are the carriers of coking properties of coals begin to form in the peat, and on the other hand, the coking property appears only during the change of brown coal to bituminous coal as a result of metamorphism; in other words, the formation of the petrographic features responsible for the coking properties depends on a primary characteristic, while the appearance of these properties depends on a secondary characteristic" (p. 83).

Here one misunderstanding follows from another. In the first place, the coking property does not appear at the boundary between brown and bituminous coal in the coal series but within the bituminous group between the long-flame and gas coals. And this is not based on geologists' concepts but on the experience of coal chemists and coke technologists. Geologists have never made statements to the contrary.

In the second place, if the character of the colloidal mass of bright coals (vitrain, xylo-vitrain, matrix) is already predetermined at the peat stage, and if it is this mass that endows coal with its coking properties, it still does not follow that peat must possess these properties. Peat has a potential capacity for coking, but it is first realized only with gas coal, after certain changes have occurred. This capacity reaches its maximum in the fat steam coals and, in part, in the coals intermediate between fat steam and coking coals and begins to diminish in coking and lean coals. The indication of this change, all other conditions being equal, is the variable thickness of the plastic layer (y). But the coals mentioned above are not primary, but represent transitional stages in the metamorphic series; i.e., they are products of a secondary process. Where is the contradiction? This is not theory but fact. A regular gradation of bright coals from long-flame to anthracite can exist within the same bed, as for example in the Donets basin (west to east).

"Theoretical" or "artificial" is the view that the series of types of coal is the same as the natural coal series and is genetically connected with it. This is accepted by a number of institutes of coal chemistry (for example DONUGI). But it is not "theory" that "types of coal" characterizing its various coking properties are causally related to definite geologic factors and are distributed in a regular way in the coal basin. Their regular zonation makes it possible to predict that type of coal in different parts of the basin or from depths which have not yet been reached by mining operations.

But we do not consider metamorphism as the only and absolute cause of coking. Thus the fusain coal of Shuraba or Sulyukta will not coke whatever its degree of metamorphism. On the other hand, the clarain-vitrain coal will always coke even at the intermediate stages of coalification (according to the content of volatiles, carbon, etc.). This has been known for a long time, and has been substantiated by many facts and is not contradictory. Coking property is a function of two independent variables.

But in his point d Zabramny asks "How can coals change according to a single

cheme when their properties depend on the nitial material, conditions of accumulation, ne amount of water in the peat, the chemi- al character of the medium and metamor- hism" (p. 83).

In the first place, the coal series of the eologists is not at all invariant, although he general trend of metamorphism towards certain limit is. In the book to which abramny refers (Yu. A. Zhemchuzhnikov, 948), it is explained in adequate detail, on p. 206-212, how various constituents of oals and therefore different types of coal hange optically and in hardness.

Among the conclusions to Z. V. Ergol'- kiy's investigation of the Donets coals, wo will be cited (p. 208):

"1. The process of coalification affects ll constituents of coal.

"2. The general direction of the changes s not equally manifested by all coal con- tituents. Changes of the same kind go on t different rates in the different substances, lthough they finally approach the same imit."

In a number of places, it is pointed out pecifically that fusain behaves very inde- endently and that the classification of Donets coals according to types does not pply to fusain-xylene coals. But the evolu- ion of all components of the colloidal mass as more or less the same trend although, s Bogolyubova's diagram shows, it pro- eeds at different rates.

All these differences and effects of the wo main factors have been clarified by a arge amount of experimental work, can be lemonstrated and analyzed under the micro- scope, and therefore do not contain contra- lictions and obscurities. It is not a rare ase in science that a favorable combination of two independent factors is required for a henomenon to reach its maximum effect.

If a coal petrographer tried to explain Zabramny's coal series he would say that he series of non-coking coals from peat to nthracite is that of fusain coals but he would find it difficult to write the series: gas coal -- fat steam coal -- coking coal.

The series of coking coals from peat to nthracite is a series of coals with amor- phous material; for example, in Donbas, in he west, there are Middle Carboniferous, rue brown coals while in the old Donbas here are all types of coal from long-flame o gas and higher.

In summary it should be said that Zabramny's experiments are interesting and useful, especially the experiments with hy- drogenated coal. It is very important to consider the nature of the initial coal (fusain, clarain, etc.). It is important also to investigate and describe the nature of the resulting products in great detail both chemically and petrographically.

It is very unfortunate that Zabramny in his account and criticisms of geologists' views expressed mainly bewilderment, did not grasp their substance, and did not con- sider the geologic factors in the different coal basins. Only mutual understanding and knowledge of at least the fundamentals of geology and coal chemistry can bring about fruitful explanation of the phenomena which lie at the borderland between the two sciences of geology and chemistry.

COMMENT ON THE STRATIGRAPHIC DICTIONARY OF THE U. S. S. R.

To complement the articles by V. A. Grossgeym, V. Ye. Khain and T. A. Sikstel' on the shortcomings of the *Stratigraphic Dictionary of the U. S. S. R.*, edited by VSEGEI and published in the Izvestiya of the U. S. S. R. Academy of Sciences, Ser. Geol., No. 10, 1957, it should be pointed out that the Dictionary does not contain certain terms much used at home and abroad, such as Anthropogene, Anthropozoic, Günz, Mindel, Riss, Würm, Neo-Würm, in spite of the fact that they appear in the works of Academicians A. P. Pavlov and I. M. Gubkin and in a number of papers in the published collection of reports read at the All-Union Conference on the Study of the Pleistocene in May, 1957, and that the term Anthropozoic Era is acknowledged by the Czechoslovak Academy of Sciences, which, in the period from 1951 to 1955, published five volumes under the general title *Anthropozoikum*.

A. M. Zhirmunskiy

TO THE EDITORS OF "IZVESTIYA OF THE U. S. S. R. ACADEMY OF SCIENCES GEOLOGICAL SERIES"[1]

In reply to N. A. Kudryavtsev's letter printed in the "Izvestiya, Akademiya Nauk SSSR, Ser. Geol.," No. 4, 1957, please print the following in your journal.

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[1]With the printing of G. I. Teodorovich's letter, the Editors terminate the prolonged (continued on following page)

From a number of statements given in my paper (Izvestiya, Akademiya Nauk SSSR, Ser. Geol., No. 8, 1956) N.A. Kudryavtsev selects only two: on the occurrence of petroleum in the basement complex of the Ural-Volga region and on the sulfide-siderite facies of the coal-bearing formations, both of which he interprets incorrectly.

1. Kudryavtsev declares that I deny the existence of occasional petroleum indications in the basement gneiss and weathered gneiss of the Ural-Volga region. Actually I deny not the existence of these indications which are related to the petroliferous Middle and Upper Devonian sedimentary cover of the basement, but Kudryavtsev's assertion that "the petroleum rises along fractures" from the basement rocks. It should be pointed out that the cores from boreholes P-7, P-6 and P-5 at Shugurovo (Devonian and basement rocks) were studied by me personally, while Kudryavtsev relies mainly on notes from the reports of the "Tatnefterazvedka" for 1947 and 1953, which were taken for him partly by Z.L. Mamin, and on Ye. I. Tikhvinskaya's report read, apparently, in May 1954, at the Conference on Petroleum Geology at Kazan. However, this report was not given at the Conference and has not been published in its Transactions (see [2]). Furthermore, gneiss and granitic gneiss belonging to the siliceous group of igneous and metamorphic rocks are locally eluviated at Shugurovo (for example, in the upper part of borehole P-7). According to Kudryavtsev's statement, however, only basic igneous rocks can be petroliferous.

Therefore, petroleum occurrences in siliceous igneous rocks, granite, gneiss, etc., must be secondary according to sedimentary and magmatic theories of the origin of petroleum.

It must be mentioned that the very existence of slight oil indications in the basement rocks in the Shugorov borehole No. 5 has not been firmly established.

Inasmuch as Kudryavtsev refers also to one of the boreholes in the Kabyk-Kupersk area, I find it necessary for the sake of accuracy to cite a passage from the letter of the Chief Geologist of the "Tatnefterazvedka," A.M. Mel'nikov, to Academician S.I. Mironov, in 1955: "In the Abdi borehole No. 2 in the Kabyk-Kupersk area, slight indications of oil in the form of slight, spotty soaking of rocks were found in the eluvium of the crystalline basement rocks. Tests on the eluvium gave a weak flow of salt water, but no signs of petroleum. The petroleum indications in the eluvium are evidently due to lateral migration, for in the Abdi borehole No. 2, the eluvium is overlain by the Kynovsk sediments where the Pashiysk and Zhivetian deposits, preserved in more deeply buried parts of the slope of the northern dome of the Tatar upwarp, wedge out."

If Kudryavtsev considers the occasional, slight indications of petroleum in the gneiss and weathered mantle within the Ural-Volga region as oil seepages, then why are there no indications of petroleum or oil pools in the crest and on the limbs of the Voronezh "crystalline" massif? Why are no petroleum indications known from Fennoscandia, etc.?

The answer to these questions is perfectly natural. The indications of petroleum in the basement of the Ural-Volga region are derived from the Zhivetian and lower Frasnian petroliferous sediments.

This is quite clear in the region of the villages of Kabyk-Kuper, Abdi and Vyatskaya Polyana, located on the rather strongly uplifted periphery of the basement [1], directly overlain by the Kynovsk beds and, farther west, by Pashiysk sediments. The thickness of the Tournaisian and of the majority of the Devonian deposits in the region of the Kabyk-Kuper borehole No. 1 decreases as compared with the western sections; Kynovskii beds here lie directly on basement rocks, whose surface in borehole No. 1 at Kabyk-Kuper gave the highest known (as of 1952) absolute elevation (-1505 m) within the Tatar upwarp. This, as it turned out, is the most elevated part of the northern dome of the upwarp. These structural relationships favored lateral or step-by-step migration of hydrocarbons from the petroliferous sediments lying in the basin to the south.

2. In his letter, Kudryavtsev gives a "small factual note": "The coal-bearing deposits, which are characterized by a strong development of the 'petroliferous' sulfide-siderite facies of G.I. Teodorovich, accumulate not only in 'freshwater, or at the most brackish, swamp waters . . .' but also under nearshore marine conditions (in the so-called paralic coal-bearing sediments)."

Kudryavtsev refers to the sulfide-siderite facies in the coal-bearing sediments as necessarily petroliferous. But I regard this facies as possibly petroliferous (1949-1954)

(continued from preceding page)
discussion initiated by the papers of S.I. Mironov and N.A. Kudryavtsev (No. 4, 1954; No. 4, 1955). Further discussion of the hypothesis of inorganic origin of petroleum must await collection of new, carefully documented and checked data.

nly where marine or other salt-water sedi- nents are present and only if they contain a ufficient amount of organic matter of the apropel type.

Kudryavtsev attempts to ascribe to me an pinion that the various coal-bearing deposits ormed in fresh or brackish waters; but I tated this only in connection with the sedi- nents of swamps and streams. In the alter- ation within each cycle of a paralic coal- earing sequence from freshwater alluvial nd peat bog to marine, it is evident that he section must also contain brackish water ediments which may belong partly to the ulfide-siderite facies. The sediments of the atter, especially on the periphery of the asin, near the sea, may well be petrolif- rous.

G.I. Teodovorich

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CHRONICLE

CTIVITIES OF THE JOINT COMMITTEE ON THE "LAWS OF DISTRIBUTION OF CONOMIC MINERAL DEPOSITS" IN 1957

The investigation of the laws of distribution the principal economic minerals in the th's crust has attracted much attention in ent years, for it has a very real impor- ce in the overall development of Soviet logy. This approach to the geologic study our country was suggested by Academician S. Shatskiy in 1953, and two years later Presidium of the U. S. S. R. Academy of ences created a special Joint Committee er Shatskiy's chairmanship to organize guide this research program.

We have already reported in the press on problems faced by the Committee in the ly stages of its work (Sovetskaya Geolog- No. 59, 1957). Below we shall acquaint reader with its activities in 1957.

It should be noted first of all that re- rch on the laws of distribution of economic neral deposits has already been advanced siderably during the last year and may be ided into three main areas: 1) studies of principal economic minerals, 2) complex ional metallogenetic studies and 3) meth- logic works.

Very interesting results have been ob- ned in many of the research projects in 7. The Committee submitted to the press ollection of 24 articles in which some of se results are at least partially discussed. main section of the collection deals with gmatic ores of ferrous, non-ferrous and nor metals. The large regions used to strate the laws of distribution of economic neral deposits are mainly our eastern ter- ries: the Urals, Kazakhstan, Altai-Sayan ion, Transbaikal, the Northeast of the S. S. R. and a few others. Until now, nei- r the domestic nor the foreign literature devoted so much attention to the laws of tribution of economic mineral deposits. ides important theoretical generalizations, collection contains material relating di- tly to scientific prospecting and prognosis.

At the committee meetings, both general tallogenetic problems and the specific blems of areal distribution of deposits of metals and non-metals such as mercury, boron, titanium, cobalt, zinc, lead, copper, silver, gold and some other important metals were discussed.

General metallogenetic problems were discussed in E. E. Zakharov's report (Mosk. Geol. -Razved. In-t) on the geologic laws of distribution of non-ferrous and ferrous met- als. The author presented a number of world maps (at a scale of 1:25, 000, 000) showing the distribution of the ores of iron, manga- nese, chromium, silver, lead, zinc, copper and tin in relation to the largest tectonic features of the earth, grouped according to the age of folding. These maps suggest cer- tain general relationships in the localization of different genetic groups of ores. This work will be of great importance for further similar investigations because no metallo- genetic maps of the world have yet appeared in the literature.

Two reports were given on the regularities of distribution of mercury deposits, one by V. A. Kuznetsov (Zap. Sib. Fil., Akademiya Nauk SSSR) and the other by V. T. Surgay (Akademiya Nauk KirgSSR).

The structural analysis of the mercury- bearing zones in the Altai-Sayan region given in the first report reveals a relationship be- tween mercury mineralization and the zones of regional faulting bordering the large down- warps of Hercynian and later ages and indi- cates that the time of mineralization is post- Hercynian or even Mesozoic. The folded structures and the associated fracture sys- tems are less important in localizing quick- silver mineralization than the faults. This is characteristic of the Altai-Sayan region and not, for example, of Central Asia. Mercury mineralization is localized only in those regional faults which are a part of the belts of abyssal faulting.

V. T. Surgay studied the distribution of mercury mineralization in Kirgizia and Cen- tral Tadzhikstan. He came to the conclusion that the largest areas of antimony-mercury mineralization in these regions are located in Middle Carboniferous structures of the graben type. The marginal faults of the graben controlled the distribution of miner- alized areas, and the smaller faults

associated with them determined the position of the deposits. The ore bodies are commonly found in the crests of anticlines composed of limestones. Rich ore shoots lie at the contact between the limestones and the overlying shales.

The geology of titanium was discussed by V. V. Bogatskiy. The magmatic titanium ores, according to him, are associated with ultrabasic and alkalic ultrabasic rocks and also with the siliceous differentiates of diabase. Areally and genetically, magmatic concentrations of titanium are related to the ultrabasic differentiates of basic, probably gabbroid, magma. Among the magmatic concentrations of titanium, of the greatest economic importance are those ultrabasic rocks formed by the differentiation of basic magma in large fault zones.

Bogatskiy presented a map of relative concentration of titanium which shows not only the regions where new magmatic titanium deposits are likely to be found but indicates also the promising areas for placer and metamorphic titanium deposits (the most promising areas are specially marked).

The paper by L. I. Shabynin (In-t Geol. Rudn. Mesturozhd; Petrogr. Mineralogii i Geokhimii, Akademiyz Nauk SSSR) is devoted to the conditions of formation and distribution of endogene borate deposits in the skarns of the eastern regions of the U. S. S. R.

It discusses the distribution of endogene borates in magnesian skarns in relation to tectonic conditions, the facies of the metamorphosed sedimentary rocks, the character of volcanic activity, the composition and age of the igneous rocks, the structures of the region and also the relation to other mineralization, especially to the composition of the associated (or principal) mineralization, to the general boron content of the region, and to the various stages of metamorphism.

Endogene borate deposits in magnesian skarns are found only at the contacts between dolomite and large granitoid bodies of different ages and are accompanied by some type of metallic mineralization. They occur in a variety of structures except frontal downwarps and platforms of post-Cambrian age. In the latter, the boron silicate mineralization may be absent even in the regions of large ore deposits.

The distribution of cobalt deposits in the caledonides of the Altai-Sayan mountain region was discussed by V. A. Unksov (Vses. N.-I. Geol. In-t). He showed that the antimony-copper-nickel-cobalt deposits in the Siberian caledonides have a rather definite and characteristic area of distribution which coincides in the main with the belt of the later depressions of the Gorny Altai and Tuba. The overwhelming majority of deposits of this type lie on the margins of the depressions and are concentrated in the regional fault zones which border them. It was possible to determine a number of local patterns of distribution of cobalt deposits on the basis of regional structural studies, and many of these have already been confirmed by exploration.

Some problems of distribution of polymetallic ores were touched upon by F. K. Shipulin (In-t. Geol. Rudn. Mestorozhd., Petrogr., Mineralogii i Geokhimii, Akademiya Nauk SSSR).

On the basis of a detailed study of the ores and petrographic analysis in the Zyrya ore deposit of the Rudnyy Altai, the author came to the conclusion that the Upper Paleozoic polymetallic and rare-metal mineralization is associated there with intrusives belonging to three age groups.

The earliest stage of mineralization was related to the large batholithic intrusions of granodiorite of the early phases of the tectonic-magmatic cycle (Zmeinogorsk granitoids"). Mineralization in the form of strong pyritization was superimposed upon greisenization. During the same stage, very likely, small lead-zinc deposits were formed such are related to granodiorites in other regions (e.g., Sekisov deposit).

The second stage of mineralization was characterized mainly by the formation of complex lead-zinc and molybdenum-tungsten deposits and was genetically and spatially related to the intrusions of the young "Kalbinsk" granitoids. During the third and late stage of mineralization, all principal polymetallic deposits were formed which are paragenetically related to the complex of dikes of basic and intermediate composition.

The first two types of mineralization were controlled by the distribution of the parent granitoids and occur either in the granitoids or at contacts in the intruded rocks.

The distribution of deposits formed during the third stage is determined by linear fault zones associated with the so-called Northeastern zone of deformation, and small intrusives are also localized in these zones and serve as important guides to ore.

E. T. Shatalov (In-t. Geol. Rudn. Mestorozhd., Petrogr., Mineralogii i Geokhimii, Akademiya Nauk SSSR) and V. T. Matveyenko discussed the very interesting problem of the relationship between faulting, magmatism and mineralization in the Northeast of the U. S. S. R.

Γhe authors present the history of igneous .vity of the region against the background :he geologic structure of Northeastern Asia, outline the pattern of distribution of its ıcipal economic minerals. The role of ting is emphasized. A number of mineral-l belts differing in composition, age, and ; are outlined. The largest of these espe-ly strongly mineralized belts is the Yana-girka-Kolyma belt of gold lodes and plac-associated with Upper Jurassic pre-batho-dikes. The Severnyy, Glavnyy and kystabyt belts are of about the same size are related to the satellites of the Kolyma nitoid batholiths. The first two border the tral Kolyma massif and contain deposits :are metals; the third is associated with Okhotsk massif. Within the belt of thick taceous Okhotsk-Chukotsk extrusives lies ıolybdenum belt related to the Okhotsk, er Cretaceous granitoids. In the Koryak-ıchatka region, the antimony-mercury belt ocalized in the Tertiary folded zone. The ılarities in the distribution of gold, tin, ;sten and other ores enabled the authors nake practical suggestions for further loration.

iuch, in brief, is the content of the scien-: reports heard by the Committee. As for administrative work in 1957, it was con-ned mainly with planning and coordination nvestigations.

Γhe principal planning document of the nmittee is the "Notes on the Main Direc-s of Research for the Sixth Five-Year ı" and an outline of the scientific subjects oe studied.

Γhe unified Five-Year plan of work for 7 made earlier by the Committee was :ussed and improved. For this purpose, ing the first half of the year, seven Joint nmittee coordination meetings were held the discussion of deposits of boron ores, sphorite, bauxite, molybdenum, cobalt and :el, polymetallic ores and mercury. These ɜtings were attended by the representatives :he Academies of Sciences of the Kazakh, giz, Azerbadzhan, and Tadzhik republics; :he Urals, Kola, East Siberia and Far t affiliates of the U.S.S.R. Academy of ɜnces; of territorial geologic administra-ıs of the Urals, Krasnoyarsk and Armenia; of many geologic institutes of Moscow, Leningrad and other organizations.

Γhe Committee intends to work further on improvement of the plan but its efforts l be directed mainly to the control of its cution. The completion of the outlined dies will make it possible to ascertain the ularities of occurrence and the areas of :ribution for a number of important eco-ıic minerals and to provide a more substantial basis for prognosis.

Among the important undertakings of the Committee was the Conference on the Metallogeny of the Caucasus organized at Tbilisi in May, 1957, by the Caucasian Institute of Raw Mineral Materials (see Izvestiya, Akademiya Nauk SSSR, Ser. Geol., No. 3, 1958). The importance of such conferences, which provide effective aid to the Committee in its work on the distribution of economic mineral deposits, must be emphasized.

The great volume of work in connection with "The Laws of Distribution of Economic Mineral Deposits," by the numerous organizations of the Academy of Sciences, academies of the constituent republics, the Ministry of Geology and Conservation of Mineral Resources, the territorial geologic administrations and other organizations, made it necessary for the Committee to organize a number of territorial working groups for coordination and scientific guidance of research in the large geologic regions. Four such groups were created during the year: the Northeastern (I. E. Drabkin, Chairman), the Ural (A. A. Pronin, Chairman) the Central Asian (Kh. M. Abdullayev, Academician Acad. of Sci. UzbSSR, Chairman) and Kazakhstan (Academician K. I. Satpayev, Chairman). The work of individual groups shows that they aid greatly in broadening and deepening the investigations of the assigned problems. At present the Committee is faced with the task of organizing smaller groups for Siberia, Transbaikal, Primor'ye, the Ukraine, the Caucasus and other regions.

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These are the problems to which the Committee devoted much attention during 1957. In the early stages the efforts of the Committee were directed towards attracting the attention of a wide circle of specialists to the study of the laws of distribution of economic mineral deposits, and by now a number of such investigations have already been completed. The next problem facing the Committee is to have these investigations published as soon as possible because many of them have immediate importance in the search for ore deposits.

On the other hand, the general investigations must be immediately utilized in work designed explicitly for the discovery of mineral deposits. Of great importance in this connection will be the compilation of metallogenetic maps at intermediate scales (1:500,000 and 1:200,000) and maps designed specifically for exploration work so essential in scientific prospecting.

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